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An analysis of NCO availability performance metrics and their relation to availability performance

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MONTEREY, CALIFORNIA

THESIS

AN ANALYSIS OF CNO AVAILABILITY PERFORMANCE METRICS AND THEIR RELATION TO AVAILABILITY PERFORMANCE

by

Matthew J. White

June 2013

Thesis Co-Advisors: Clifford Whitcomb
Patricia Jacobs

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The Navy's approach to planning and executing Chief of Naval Operations maintenance availabilities has undergone significant changes since 2006. The adoption of unique lean initiatives and defined project management fundamentals have guided shipyard and project leadership as they manage scheduled industrial maintenance for ships and submarines. These business practices have resulted in performance measurement and control data being gathered for shipyard management to use as they analyze availability performance. This thesis reports on the results of exploratory analyses of these data to evaluate associations and trends pertaining to cost and schedule performance since the inception of the lean initiative. The study's analyses suggest that numerous performance metrics display trends which suggest availability performance is improving over the defined lean initiative time frame; that several metrics are functions of the length of the individual availability and require appropriate weighting considerations; and that average weekly interim production bow wave metrics evaluated early in an availability may have predictive abilities concerning availability completion success.

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AN ANALYSIS OF CNO AVAILABILITY PERFORMANCE METRICS AND THEIR RELATION TO AVAILABILITY PERFORMANCE

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The Navy's approach to planning and executing Chief of Naval Operations maintenance availabilities has undergone significant changes since 2006. The adoption of unique lean initiatives and defined project management fundamentals have guided shipyard and project leadership as they manage scheduled industrial maintenance for ships and submarines. These business practices have resulted in performance measurement and control data being gathered for shipyard management to use as they analyze availability performance. This thesis reports on the results of exploratory analyses of these data to evaluate associations and trends pertaining to cost and schedule performance since the inception of the lean initiative. The study's analyses suggest that numerous performance metrics display trends which suggest availability performance is improving over the defined lean initiative time frame; that several metrics are functions of the length of the individual availability and require appropriate weighting considerations; and that average weekly interim production bow wave metrics evaluated early in an availability may have predictive abilities concerning availability completion success.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AIM-NG	Advanced Industrial Management − Next Generation
AQWP	Actual Quantity of Work Performed
ASD	Actual Start Date
BQWP	Budgeted Quantity of Work Performed
CNO	Chief of Naval Operations
CVN	U.S. Navy Aircraft Carrier
DoD	Department of Defense
DPL	Daily Priority List
JFMM	Joint Fleet Maintenance Manual
JRC	Job Readiness Cell
LWK	Last Week
NAVSEA	Naval Sea Systems Command
NNSY	Norfolk Naval Shipyard
NPS	Naval Postgraduate School
NSSG	Naval Systems Support Group
NWK	Next Week
OMN	Navy's Operations and Maintenance Account
OT	Overtime
PHNSY	Pearl Harbor Naval Shipyard
PMC	Performance Measurement and Control
PNSY	Portsmouth Naval Shipyard
PSNSY	Puget Sound Naval Shipyard
PSS	Project Sequencing and Scheduling
PTL	Partial
REL	Released
RMC	Regional Maintenance Center
RPD	Resources Per Day
SE	Standard Error
ST	Straight Time
SY	Shipyard

TWK	This Week
USN	United States Navy
WIP	Work in Process
WIPCON	Work in Process Control
WKG	Working

EXECUTIVE SUMMARY

This exploratory study examines the project management practices and metrics used during the execution of Chief of Naval Operations (CNO) maintenance availabilities. Since 2005, CNO availabilities have undergone considerable changes stemming from process improvement initiatives and increased scrutiny of project management metrics. As the Navy attempts to optimize the performance of CNO availabilities, critical topics of interest among industrial-based maintenance commands include the relationships between project management metrics and the Navy maintenance enterprise. A more defined and clear understanding of these complex relationships will equip project leadership with improved decision-making capabilities and translate into improved schedule and cost performance for completed CNO availabilities.

The scope of this research covers CNO maintenance availabilities completed since the inception of Naval Sea Systems Command's (NAVSEA) Lean Release initiatives in 2006. The maintenance projects studied include varying availability types and lengths, but generally involve submarine and aircraft carrier upkeep periods and overhauls. In addition, several amphibious vessels and tenders are included in the study's data set.

Data used in this research were collected by the four U.S. naval shipyards and compiled by the Naval Systems Support Group in Norfolk, Virginia. The two sets of data examined cover both end-of-availability metric averages and interim-availability weekly metric data. The first set analyzed includes the average metric data computed at the end of the availability for 85 completed CNO availabilities with completion dates ranging from 2006 through 2012. The second set includes the same types of availabilities, but includes weekly performance metric data allowing for a more detailed analysis of specific availabilities.

The major findings of this study are as follows:

Various summary metrics computed at the end of any availability display trends since the time lean release initiatives were initiated. In particular, it was found that

average manning percentage and average work in process tends to decrease over time. Average closed work and average throughput tend to increase over time. These trends suggest that the initiatives are having the desired effect of positively influencing schedule and cost performance. The average production bow wave metric computed at the end of the availability has no trend. The values of metrics including days late, float, and cycle time are functions of the length of the availability. We recommend that these metrics be divided by the availability length. The metric computed by dividing the number of days late by the length of the availability has no apparent dependence on shipyard or time of availability completion.

Five pairs of availabilities are chosen from the second data set having weekly metrics; one having desirable availability characteristics and one having undesirable characteristics. Each pair represents a pre-determined availability type (submarine or aircraft carrier, long or short availability) and included one successful and one unsuccessful availability according to NAVSEA cost and schedule performance standards. Summary statistics of the weekly project performance metrics for the first 30 percent of the weeks are computed for each availability in the pair and compared. The summary statistics of the five availability pairs suggest the following:

- During the first third of an availability, desirable availabilities tend to have lower average bow wave percentages than undesirable availabilities, with a range between 20–40 percent bow wave.
- During the first third of availability, desirable availabilities tend to maintain higher throughput percentages than undesirable availabilities.

The value of this study revolves around both its robust analysis of project management metric associations and the strong foundation it lays for future exploration of CNO availability performance. While the data sets utilized in this study exhibit a spectrum of availability performance, it is the recommendation of this study that future work-study metrics computed during the availability rather than summary metrics at the end of the availability.

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I. INTRODUCTION

A. CONTEXT

In an era challenged by global economic uncertainty and large national debt in the United States, U.S. defense funding has experienced a sharp increase in strict oversight and contentious deliberation while the country begins to cut expenses and reduce the financial deficit. Additionally, as the wars in Iraq and Afghanistan come to an end, the U.S. military has found it more difficult to garner the reliable financial support it came to expect from the federal government at the height of the wars. Lawmakers are especially critical of defense spending as these wars conclude, and military leadership is now charged with managing the force under reduced budgetary allowances. Specifically, in early 2013, the Chief of Naval Operations (CNO) outlined how funding under the current Continuing Resolution and impending sequestration would impact the U.S. Navy. The CNO acknowledged that the Navy's Operations and Maintenance (OMN) account would experience significant budgetary reductions in the foreseeable future and foremost among his proposals were plans to cut private-sector ship maintenance availabilities and aircraft depot maintenance. In addition, he has ordered a civilian hiring freeze which will significantly impact the naval shipyard maintenance workforce (Chief of Naval Operations [OPNAVN00] 2013). These actions will impact daily operations at public naval shipyards and require even more that leadership strongly emphasize the criticality of sound project management techniques and principles.

B. BACKGROUND

The Naval Sea Systems Command (NAVSEA) is the primary entity responsible for maintaining the operational fleet of ships and submarines. The four U.S. Naval shipyards fall under the direct control of NAVSEA 04, the NAVSEA directorate responsible for logistics, maintenance, and industrial operations (Naval Sea Systems Command [NAVSEA]04Z, 2011). Consequently, as private-sector ship maintenance is cut from the budget, it will fall upon NAVSEA 04 and the four naval shipyards to meet the operational requirements of fleet and combatant commanders requiring ships and submarines in their respective areas of responsibility.

1. CNO's Vision for Navy Fleet Sustainment

The 2009–2013 NAVSEA Strategic Business Plan outlines three primary objectives for efficiently and effectively sustaining today's U.S. Fleet (NAVSEA, 2009):

- To develop annual balanced, optimized, integrated and funded Maintenance and Modernization Execution Plans for shipyards and Regional Maintenance Centers.
- To execute the Maintenance and Modernization Execution Plan and develop metrics to monitor the results.
- Apply Continuous Process Improvements to reduce maintenance Life Cycle costs.

Of these objectives, two pertain directly to the directives identified in the NAVSEA 2006 Lean Release 2.0 Recommendation. In the release, six process improvements were recommended for adoption and specific validation metrics were defined for each process improvement.

2. LEAN Release 2.0 Recommendation

The Naval Sea Systems Command (NAVSEA) promulgated a set of 6 process improvement initiatives for the four U.S. Naval Shipyards in their September 2006 "Project Management Lean Release 2.0 Recommendation." The recommendation identified process improvements related to project execution priorities, execution support, project execution, and resource allocation (NAVSEA 04X, 2006). Specifically, the initiatives included:

- Project workload prioritization
- Job readiness
- Work-in-progress control (WIPCON)
- Resource allocation
- Troubleshooting support (Andon)
- Overtime allocation

By improving the efficiency associated with of each of these process stages, NAVSEA intends to improve overall shipyard cost and schedule performance on CNO maintenance availabilities. These process improvement initiatives are all aligned toward the primary shipyard goal of ensuring non-stop execution of each project's critical chain work.

3. Navy Maintenance Stakeholders

Various sponsors, operators, suppliers and contractors share a vested interest in CNO maintenance availabilities for ships and submarines. The demand placed on the Navy's maintenance system is not solely influenced by operational needs and requirements. The main objective of ship and submarine maintenance is to deliver capable and reliable warships to operational commanders for national defense tasking, but several other stakeholders are critical to mission accomplishment. First, ship maintenance leadership must ensure that they are carrying out duties as effective and efficient stewards of government funding. The Department of Defense (DoD) and Department of the Navy promulgate guidance on program, acquisition, and industrial management, but it is the responsibility of shipyard leadership to execute that guidance and deliver value. Furthermore, in some regions, entire communities are built around the military industrial enterprise. Numerous individuals are employed directly by the DoD and many others work for private defense companies which rely on the contracts provided by DoD. Administratively, individual commands within NAVSEA work together to meet the needs of each other and each respective stakeholder. The stakeholders are listed below.

a. Department of Defense/Department of the Navy

These sponsors represent the U.S. government and retain the administrative authority to direct funding and establish guidance for Navy ship and submarine maintenance. Like combatant and fleet commanders, they seek to meet operational commitments and demands, but manage these efforts from a holistic perspective balancing operations with policy and fiscal control. They are accountable for delivering national defense to the U.S. civilian populace.

b. Combatant/Fleet Commanders (Operational Forces)

These entities require that ship and submarine maintenance teams plan, manage, and execute maintenance which meets both operational requirements and schedule constraints. Both planned overhaul work items and emergent repairs must meet a high level of quality and be conducted within a reasonable time frame. Essentially, every warship undergoing shipyard maintenance is a warship unavailable to operational commanders, and it is imperative that availability completion is on time to satisfy the ship's operational commitments.

c. Private-sector Military Contracting Industry

This group includes the companies and organizations which provide consulting services, equipment, labor and supplies to the Navy industrial system. The Navy relies on these stakeholders when a project or work item lies outside of the naval shipyard's capability or when cost considerations dictate contracting the work.

d. NAVSEA 04

This directorate of NAVSEA is the executing command of Navy shipboard industrial operations and the parent command of all four naval shipyards. NAVSEA 04 manages shipyard policy, planning, and high-level operations (NAVSEA 04Z, 2011).

e. Navy Systems Support Group (NSSG)

NSSG is a support office within NAVSEA 04 which is responsible for tracking, analyzing, and refining shipyard performance and process control. They are responsible for data collection and analysis, as well as the recommendation and implementation of process improvement measures at shipyards and industrial activities (NAVSEA 04Z, 2011). While several other small stakeholders may exist within the realm of Navy ship and submarine maintenance, these groups cover all those within the scope and focus of this research.

C. PAST CNO AVAILABILITY RESEARCH

Recent NPS alumni, Dan Leszczynski and Joe Caprio, completed a preliminary investigation into CNO Availability schedule overruns in the summer of 2012. Their research hypothesized that business practices involving resource planning, overtime, and work stoppages adversely impacted the timely completion of availabilities. Using data sets similar in composition to the sets analyzed in this study, they found strong associations pertaining to availability hull-type and trends involving the cost performance of timely and late availabilities; monthly work costs compared to the budgeted amount of planned work for late availabilities; and the frequency of work stoppages as related to availability completion timeliness (Caprio & Leszczynski 2012). Their conclusions were reviewed and considered during the initial stages of this research effort and were used to develop the research questions, scope, and problem statement of this thesis.

D. PROBLEM STATEMENT

The constant effort to achieve a balanced approach among resources, work items, and schedule during naval shipyard maintenance availabilities is monitored by NAVSEA 04 using nine performance-based metrics (NAVSEA 04X, 2012). Shipyard and project leadership calculate and assess these metrics regularly to determine if schedule and resources are being utilized effectively in the completion of work packages. The change in these metrics over the period since NAVSEA's Lean Release 2.0 was released is studied. In addition, associations between the nine metrics and availability completion lateness are explored. Such retrospective data analyses will result in improved application of performance metrics to operational planning and decision-making carries reduced legitimacy.

E. RESEARCH QUESTIONS

Specific research questions tailored to guide the study's approach and execution are:

- Are performance-based metrics for CNO availabilities improving over time and since the inception of NAVSEA's Lean Release?
- Have process improvement initiatives improved cost and schedule performance in CNO availabilities?
- Are performance metrics comparable for availabilities of different lengths?
- How do specific performance metrics impact and influence other performance metrics?
- At what frequency should specific metrics be computed?

F. SCOPE OF THE THESIS

The breadth of this thesis will address a majority of the process improvement initiatives outlined in NAVSEA's Lean Release 2.0 through statistical analyses of the performance metrics adopted to track their progress. The main topics covered in this thesis will include:

- Changes in availability metric performance over the time period covering LEAN Release (2006–2013).
- Associations specific to an availability's overall Work in Process in relation to other key performance metrics.
- Influence of availability length on availability performance and associations among performance metrics for those maintenance availabilities.
- Proposal and study of modified metrics which are the original metrics weighted to account for availability length when the original metric fails to provide proper weighting.
- Evaluation of metric performances in early and on time availabilities compared to those in late availabilities.
- Recommendation of the frequency at which metrics should be computed during a project so that specific metrics can be viewed, analyzed, and presented in order to portray accurate and relevant availability performance.

- Inspection of weekly CNO availability data to study if metric data collected during the early stages of an availability can predict availability success or failure.

It is the goal of this study to reveal as many trends and associations between performance metrics as is possible within the data sample sets provided. While the size of the data sets being considered may not be large enough to provide statistically significant results regarding all shipyard maintenance and project management metrics, they can detect convincing trends that will afford project management teams the ability to employ new strategies while executing CNO availabilities. Additionally, analysis which uncovers encouraging conclusions will help to scope and guide future investigative efforts involving naval shipyard project management fundamentals and performance metrics.

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II. CNO AVAILABILITY PROCESS IMPROVEMENT

A. INTRODUCTION

This chapter provides the framework through which NAVSEA directorates and the public naval shipyards approach process improvement initiatives in shipyard operations. In addition, it addresses the purpose of CNO availabilities and defines the types of availabilities covered in this thesis.

B. PROCESS IMPROVEMENT METHODS

In this section, the Theory of Constraints and Lean Six Sigma models will be discussed to provide conceptual understanding and emphasize their utility to process improvement.

1. Theory of Constraints

The Theory of Constraints is a project management improvement methodology which recognizes the importance of choosing the right projects to undertake and also identifying and executing a project's "critical chain." Defining the critical chain is crucial to completing projects faster and increasing throughput in an organization without investing additional resources (Kerzner, 2012). This ideology was first introduced and developed by Dr. Eliyahu M. Goldratt in the late 1980s and applies the following five focusing steps:

1. Identify the system's constraints.
2. Decide how to exploit the constraint.
3. Subordinate everything else to the above decision.
4. Restructure the system to exploit the system's constraint.
5. If, in a previous step, the system's constraint has been broken, go back to step 1.

While the Theory of Constraints is traditionally only referenced in relation to optimizing critical chain scheduling networks for projects, it is also the basis for Lean thinking and process improvement techniques.

2. Lean Six Sigma

Lean Six Sigma is a dual-approach process improvement initiative and the foundation of NAVSEA's Lean Releases. The initiative focuses on improving both the efficiency of a process and the quality of its output by employing Lean and Six Sigma principles, respectively. Lean is traditionally applied first, as it would be illogical to attempt improving the production quality of a not-yet efficient system. Lean seeks to identify the root cause of a process output deficiency, align the process so that only factors paramount to system success are fully engaged, and finally remove all wasteful functions which do not directly contribute to output efficiency or quality. As mentioned, the goal of Lean is to produce the most efficient process possible for producing the desired output. Six Sigma focuses on the quality of the output through minimizing process variation and disciplined adherence to process quality improvements. The term "Six Sigma" refers to a quality spread of six standard deviations or only 3.4 defects per million process outputs in an industrial setting (Kerzner, 2009).

C. NAVSEA LEAN IMPLEMENTATION

1. Introduction

Upon executing a thorough series of Lean events and conferences, the Naval Sea Systems Command (NAVSEA) promulgated a set of 6 process improvement initiatives for the four U.S. Naval shipyards in their September 2006 "Project Management Lean Release 2.0 Recommendation." The recommendation identified process improvements related to project execution priorities, execution support, project execution, and resource allocation. Specifically, the initiatives included:

- Project workload prioritization
- Job readiness
- Work-in-progress control (WIPCON)
- Resource allocation
- Troubleshooting support (Andon)
- Overtime allocation

By improving the efficiency associated with each of these process stages, NAVSEA intends to improve overall shipyard cost and schedule performance on CNO maintenance availabilities. These process improvement initiatives are all aligned toward the primary shipyard goal of ensuring non-stop execution of each project's critical chain work.

2. Discussion of Specific Lean Release Initiatives

a. Prioritization

Instead of utilizing and applying network analysis to recommend project prioritization, earlier Naval Shipyard practices based project priorities and resource allocation decisions on perceived needs and past experiences. In an age of high-speed computing and technical analysis, these rudimentary means of decision-making are both inefficient and obsolete. NAVSEA recognizes that without the application of network analysis to project prioritization assessments, it is improbable that the critical chain is being driven as efficiently as is possible and it is likely that both human and material resources are being under-utilized on projects. These inefficiencies lead to high levels of work-in-progress (WIP), high overtime rates, and late-finishing projects. The "prioritization" process change ensures that a detailed network analysis effort is at the center of scheduling and resourcing decisions.

b. Job Readiness

Job readiness refers to the pre-packaging of materials and preparation for work tasks prior to execution. Instead of aligning this process with a Daily Priority List, past shipyard task preparation was usually conducted independently and without consideration for execution priorities. As was the case for workload prioritization, perceived needs and past experiences determined packaging priorities instead of critical chain task identification. Not taking into consideration critical chain tasks resulted in the system having high levels of WIP, high inventory, multi-tasking, and a lack of consideration for execution priorities. While high levels of WIP are sometimes encouraged in shipyards because it keeps mechanics and other workers fully occupied and busy, they can also result in excessive rework, a lack of project focus and control, reduced throughput, and reduced flexibility to emergent issues. The changes to the job readiness process involve intricate alterations to "work packaging and control" and "initial fill" business rules. The goal of this process change is to ensure improved efficiency and accuracy when job readiness cells release task packages.

c. Work-In-Progress Control (WIPCON)

A project's "work-in-progress" or WIP refers to all job tasks that have been assigned an actual start date by the supervisor and are considered to be in a working (WKG) status. Within the context of WIP analysis for this thesis, WIP is measured in units called "resources per day," or RPDs, which is one eight-hour work shift by one worker. Excessive WIP levels have been identified as contributing to decreased throughput and higher project costs due to increased manning and overtime rates. Lean Release 2.0 identifies WIPCON as a corporate process which establishes a clear protocol for assigning and maintaining WIP levels at the supervisor-level. WIPCON depends on sound interaction between the first-line supervisors and the job readiness cell (JRC), the entity responsible for interpreting the Daily Priority List and pushing work into the supervisor's WIPCON Queue. The supervisor's WIP will be limited to 15 work packages and monitored by maintaining a WIP Index between 5 and 15. The WIP Index is further explained in Section D of this chapter.

d. Resource Allocation

Project resources were initially assigned to project work according to perceived customer needs and past experience, instead of sound prioritization and allocation based on network analysis. This practice resulted in overstaffing some projects and understaffing others, leading to cost and schedule problems for the maintenance enterprise. The new system incorporates a multi-pass process in assigning resources so that the critical chain and penetrating jobs are staffed before less-critical jobs. A penetrating job is one that has negative float and is therefore behind schedule.

e. ANDON

Andon is NAVSEA's new approach to resolving availability problems at the job site. It involves direct supervisor interaction and an immediate response by technical support personnel. If the job discrepancy will require follow-on review and effort, the supervisor reassigns personnel to the next prioritized job on the Daily Priority List (DPL) while troubleshooting continues. Prior to 2006, the problem resolution process involved mechanics leaving their job site to pursue troubleshooting assistance which interrupted the critical chain and created long work stoppages. While this process change was enacted to add value to the project management performance base, it will be difficult to track because it lacks direct measurable results when employed within the industrial setting.

f. Overtime Allocation

Prior to 2006, overtime reserves have been expended without consultation of network analysis information. Similar to the "prioritization" process change, "overtime allocation" now incorporates network analysis and the identification of project float to properly disburse overtime allowances. The threshold below which overtime should be held is 10 percent.

D. WIPCON OVERVIEW

1. Introduction

Of all the process improvement initiatives promulgated in the Lean Release 2.0/3.0 documents, WIPCON represents the process change integral to project management fundamentals and most availability performance metrics. While all of the process improvement initiatives have an impact on some aspect of availability performance, WIPCON involves facets of the entire industrial maintenance system. Thus, WIPCON will be discussed in further detail.

2. Discussion

In Chapter 8A of the AIM-NG Process Manual, "work in process" (WIP) is defined as the total number of task packages that have an actual start date claimed in the Daily Priority List (DPL) and are not certified. A certified task package is one that has been closed out for the availability. WIPCON, or the control of work in process, is further delineated in the chapter as a process improvement initiative which ensures the active progression of project tasks toward completion. The primary objective of WIPCON is to ensure that project tasks commence when scheduled and that supervisors and managers aggressively engage project constraints when task start dates experience delays.

In order to identify a task as WIP within the shipyard's WebAIM system, an actual start date (ASD) must be entered into the system on the day that productive work begins on the task. Once this action has been completed, WebAIM will change the job status to "working" (WKG) from "released" (REL) or "partial" (PTL). The job status is critical to identifying which task packages have started and which task packages should have started based on the as-of-date. The root cause of shipyard WIP deficiencies is failure to address and mitigate activities which have surpassed their scheduled start date. According to NAVSEA, this failure will result in an increasing production bow wave of work and inaccuracies in both resource requirements and projected Key Event and Milestone dates (NAVSEA 04X, 2012). The production bow wave is further discussed in Chapter III.

Thus, thorough analysis of the scheduling network for jobs that have not started is a major responsibility of zone managers and supervisors. This procedure is clearly shown in Figure 1, as the responsible party is presented with a clear process flow diagram for executing this task. The process consists of identifying schedule discrepancies, identifying the constraints preventing the work to start, and removing the constraint if the mechanic is available. If constraints cannot be removed, the zone manager must assess the schedule discrepancy in relation to available project float and work with the scheduler to find a resolution. Moving the planned start date of a task in the Project Sequencing and Scheduling (PSS) Database can be implemented by the scheduler, but only as a last resort (NAVSEA 04X, 2012).

Another tool developed for managers to control WIP is the Supervisor's WIP Board. A physical progress board, the Supervisor WIP Board was created to promote visibility, communication, and ownership of work by all shop and project team personnel. A copy of the Daily Priority List (DPL) and the weekly interim metrics are also posted on the WIP Board to ensure supervisors and mechanics are aware of project performance.

The main function of the board, however, is to physically store task package documents of current WIP away from the job-site and allow mechanics and supervisors to manually update and validate work (NAVSEA 04X, 2012).

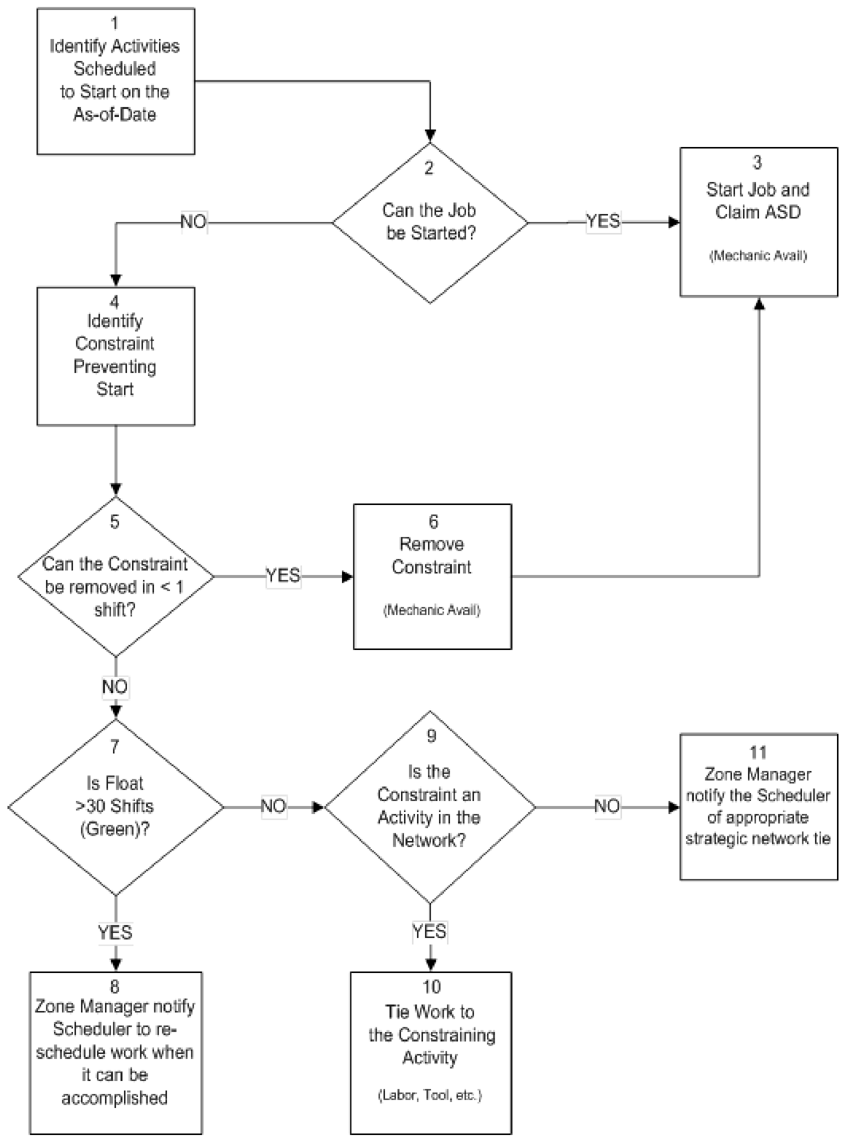

Figure 1. WIPCON Process Flow (From NAVSEA 04X, 2012)

3. WIP Metrics

In analyzing the causes and influences of Work in Process, the WIP metric must be clearly defined and explained within the context of the shipyard operations enterprise. Shipyard leadership, technical managers, and project supervisors use several different WIP calculations when presenting the metric for review or analysis (NAVSEA 04X, 2012). Fundamentally, the different calculations refer to different levels of WIP granularity. These differing calculations of the same metric are important because they show WIP at different management levels within the organizational structure. For example, the admiral and senior executives leading NAVSEA 04 want to accurately comprehend WIP levels and performance across all four naval shipyards while the project superintendent working on a specific maintenance availability wants a working metric that can be used to evaluate WIP performance at the project level. Thus, the different methods for calculating and measuring WIP are necessary, but must be clearly distinguished prior to presentation.

a. Total Project WIP

Total Project WIP presents WIP as a ratio of current work in process to the manning level assigned to that WIP. Both variables are measured in resources per day (RPD) and a RPD refers to a standard eight-hour workday completed by one shipyard worker.

$$Total\ Project\ WIP = \frac{WIP_{\ LWK}}{Straight\ Time\_RPD_{\ LWK}}$$

The Total Project WIP metric is the only WIP calculation considered in the data and analysis of this thesis. In the equation above, the numerator refers to the WIP from the previous week and the denominator is the previous week's Actual Quantity of Work Performed (AQWP) minus the overtime and divided by the number of workdays. "LWK" means last week.

b. WIP Index

The WIP Index is a measure which represents the ratio of total project WIP in CU Phases (jobs) to the number of supervisors managing that WIP. In this calculation, WIP is measured in individual work items instead of RPD. “TWK” means this week.

$$WIP\ Index = \frac{WIP_{CU\ Phases}}{\#\ of\ Supervisors_{TWK}}$$

c. Zone Manager WIP

Zone manager WIP is measured as the total number of CU Phases (Jobs) held by that zone manager and listed as open (WKG) and not yet certified. Ideally, shipyards strive to maintain zone manger WIP between 10 and 50 work items.

d. Supervisor WIP

Supervisor WIP is measured as the total number of CU Phases (Jobs) held by an individual supervisor and listed as open (WKG) and not yet certified. Ideally, shipyards strive to maintain supervisor WIP between five and 15 work items.

4. Significance of WIP Management

Along with the production bow wave, WIP is actively managed but not directly controlled like resource or schedule inputs. It is sensitive to a wide range of project management factors and a more in-depth understanding of it will undoubtedly improve CNO availability performance. Further analysis will reveal the effectiveness of WIPCON and suggest the optimal management approach concerning project WIP.

E. CNO AVAILABILITY OVERVIEW

1. Definition

CNO availabilities are defined as the scheduled periods during which U.S. Navy ships and submarines are made available for maintenance ranging from minor upkeep to complex overhauls and refueling. During these availabilities, software and hardware upgrades are made to combat systems and weapons suites; alterations can be made to a vessel's structural integrity; and the vessel undergoes numerous other cosmetic and crew-safety related improvements (OPNAV 431, 2010). The size and scope of the maintenance package is used to determine the amount of time the availability will take during initial planning.

2. Types of Availabilities

A thorough breakdown of CNO availability execution and administrative duties are explained in Ch. 3, Volume II of the Joint Fleet Maintenance Manual (JFMM). Specifically, for the purposes of this research, special attention was paid to the type and duration of CNO availabilities as described in the JFMM (OPNAV 43, 2010)

1. Overhaul. An availability, greater than six months in duration, and scheduled for the accomplishment of industrial maintenance and modernization. Overhaul availabilities include:
    - a. Regular overhaul
    - b. Complex overhaul
    - c. Engineered overhaul
    - d. Refueling overhaul (ROH)
    - e. Refueling complex overhaul (RCOH)
    - f. Engineered refueling overhaul (ERO)
2. Other longer availabilities (six months or longer) are scheduled and conducted for industrial maintenance and installation of major, high priority alterations. Types of these availabilities include:
    - a. Depot modernization period (DMP)
    - b. Planned incremental availability (PIA)
    - c. Docking planned incremental availability (DPIA)
    - d. Extended drydocking phase maintenance availability
    - e. Post shakedown availability
    - f. Carrier incremental availability
3. Shorter availabilities, lasting six months or fewer, are labor intensive and scheduled for the accomplishment of industrial modernization and modernization. Types of shorter availabilities include:
    - a. Selected restricted availability (SRA)
    - b. Docking SRA

c. Phased maintenance availability

d. Docking phased maintenance availability

e. Service craft overhaul

f. Extended SRA

g. extended docking SRA

h. Incremental SRA

i. Extended refit period

j. Post shakedown availability

k. Pre-inactivation restricted availability

F. SUMMARY

This chapter presented information pertaining directly to the on-scene management of shipyard availabilities and provided information concerning the different types of availabilities conducted at the four shipyards.

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III. NAVSEA PROJECT MANAGEMENT METRICS

A. INTRODUCTION

In chapter 10A of the AIM-NG Process Manual, NAVSEA 04 there are definitions of nine distinct and actionable metrics for use in the performance measurement and control (PMC) of shipyard availabilities. These metrics are continually gathered for specific projects, analyzed to determine project advancement and efficiency, and documented for management transparency. The nine metrics most commonly referenced include:

- Production bow wave
- Production manning
- Total percent overtime last week
- Total cost performance
- Total percent closed work
- Key event performance
- Total project WIP
- Total throughput
- Average cycle time

These measures are all influenced by a complicated set of relationships and factors within the shipyard maintenance environment. Computed based on specific quantities of work, time, and resources, they must be adequately defined for the industrial maintenance scenario they represent.

B. METRICS DEFINED

1. Production Bow Wave

The "production bow wave" metric is defined as a measure of the amount of work scheduled for the following week compared to the amount of workforce available to compete that work. Both of these variables are expressed in units of "resources per day" or RPD. One RPD is expressed as eight hours of work completed by one worker (NAVSEA 04X, 2012).

$$Bow\ Wave = 1 - \frac{Workforce\ Available_{NWK}}{Scheduled\ Workload_{NWK}}$$

In the equation above, "NWK" refers to the next or following week's workforce and workload values.

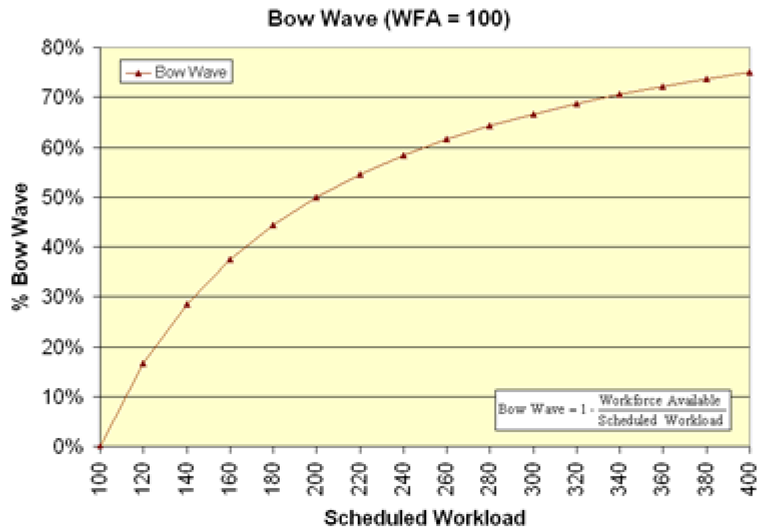

Figure 2. Bow Wave versus Increasing Workload with Constant Workforce Available

The production bow wave is a projected metric, as the values used to determine it are based on anticipated project workloads and workforces for the following week. Shipyards traditionally attempt to schedule more workload than they have resources to complete it in order to account for unscheduled resource gains and unanticipated work stoppages. Specifically, they attempt to schedule 20 percent more work than they have available resources, which would incur a 17 percent bow wave (NAVSEA 04X, 2012).

2. Production Manning

The production manning metric is essentially a determination of how close the actual manning is compared to the bow wave predicted the previous week. It is a measure of the actual, or effective, manning for the target week compared to the scheduled workload for that target week.

$$Manning = \frac{Straight\ Time_{\ TWK}}{Scheduled\ Workload_{\ TWK}}$$

"Straight Time" refers to Actual Quantity of Work Performed (AQWP) minus overtime and divided by the number of workdays. "TWK" means the cumulative value for the availability as of that week.

$$AQWP = Overtime\ (OT) + Straight\ Time\ (ST)$$

AQWP is calculated for each week at the completion of the workweek.

3. Total Overtime Percentage (Last Week)

Overtime is an important project management resource that requires close supervision. The percentage documented by shipyard management is the ratio of that week's overtime in RPD to the Actual Quantity of Work Performed (in RPD) for that week.

$$Overtime\ \% = \frac{OT_{TWK}}{AQWP_{TWK}}$$

It is important to recognize that overtime is presented in the form of a percentage. There will be a large difference between the number of RPDs assigned as overtime for a long availability and short availability for the same recognized overtime percentage because of the difference in work package size.

4. Total Cost Performance

Instead of comparing availability dollar amounts to determine cost performance, the project management metric uses the ratio of budgeted and actual resources in terms of man-hours or "resources per day."

$$Cost\ Performance\ (CP) = \frac{BQWP_{TWK}}{AQWP_{TWK}}$$

The cost performance metric is an important metric to collect and document as it is the basis for earned value management practices. BQWP refers to the "Budgeted Quantity of Work Performed." In the equation above, "TWK" refers to that week's cumulative values. The cost performance metric is cumulative; that is the numerator (respectively denominator) is the sum of all budgeted work up to and including that week.

5. Total Percentage Closed Work

Closed work percentage refers to the cumulative percentage of actual closed work for a current week (the sum of all closed work up to and including that in the current week) compared to the planned closed work according to the project schedule.

$$\%\,Closed\,Work = \frac{Allcw_{\;TWK}}{BQWP_{\;TWK}}$$

Actual closed work refers to the quantity of project work that belongs to jobs that have been closed. The planned closed work for any given week is given as the Budgeted Quantity of Work Performed for that week.

6. Key Event Performance

This metric is represented by different values depending on the point in time during which the availability is being evaluated. The two common scenarios are at the interim-availability weekly level or at the completed end-of-availability metric level.

At the interim-availability level, this metric identifies the amount of float (in days) in the schedule network prior to the next project key event or milestone. Float is the difference in the scheduling network between the latest finish date and the earliest finish date for a work item (Kerzner, 2009). An availability's critical chain work determines the summary float measure (key event performance) for the entire availability. Key events and milestones are indicators of project progress along the course of the project and are used as assessment tools for availability leadership.

At the end-of-availability level, this metric identifies the overall schedule performance of the entire availability. It will show if the availability was completed early, on time, or late as well as the number of days early or late.

7. Total Project WIP (Work in Process)

The WIP metric identified below is a weekly measure used to gauge the project's work in process level for the previous week.

$$Total\ Project\ WIP = \frac{WIP_{lwk}}{ST\_RPD_{lwk}}$$

It is a ratio which compares the manning required for opened project tasks to the level of manning currently executing the work package for that project. The numerator refers to the WIP from the previous week (in RPD) and the denominator is the previous week's Actual Quantity of Work Performed (AQWP) minus the overtime; "LWK" means last week.

8. Throughput

This metric identifies the percentage of work that has been certified to date compared to the baseline total work expected to be certified at that date during the availability.

$$TP\ \% = (Total\ Jobs\ Cert\ to\ date)/(Total\ Baseline\ Scheduled\ to\ Cert\ to\ date)$$

Certification is the key to this metric as a completed work item is not a certified work item. Certification entails official acceptance by the government for the work performed while a closed work item refers only to a job item that has been finished and no longer requires manning and resource allocations (NAVSEA 04X, 2012). This allows project leadership to differentiate between throughput and closed work during an availability.

9. Average Cycle Time

The average cycle time is the mean number of days it takes to complete a work item in an availability. Project leadership can view this at the weekly, monthly, or complete avail level. However, this metric is not weighted for the length of the availability it represents. Shipyards generally expect that longer availabilities will have higher average cycle times.

C. SHIPYARD MANAGEMENT'S INFLUENCE OVER METRICS

In this section, the metrics will be identified by the amount of control the shipyard management exerts over each metric and how they can use the metrics in their attempts to successfully manage CNO maintenance availabilities.

1. Actively-Managed Metrics

Of the nine performance metrics displayed and discussed in Chapter 10A of the AIM-NG Process Manual, shipyard leadership retains direct control over only two quantities. Leadership can actively control their resources, which means they directly influence the manning levels appropriated to each job and the overtime allotted across individual shipyard availabilities. These control variables influence the production bow wave and work in process metrics.

2. Indirectly-Managed Metrics

While followed closely and influenced by leadership resourcing decisions, the production bow wave and work in process (WIP) metric are secondary metrics dependent upon management's decisions and workload execution. Thus, while technically managed, they are far more difficult to control because they are not direct inputs. To be successfully managed, they require a delicate balancing of resources, specialized labor skills, and scheduling. Assuming this balance is achieved, and work item completion is executed as planned, these metrics should fall within the desired ranges.

3. Monitored Metrics

The remaining five metrics depend solely on workload execution. Project leadership can allocate resources correctly and attempt to control WIP and the bow wave through scheduling adjustments, but if execution of the work package faces impediments, cost performance, cycle time, closed work percentages, throughput, and key event performance can all yield undesirable results.

Currently, shipyard project managers agree that the key to successfully completing CNO availabilities within cost and schedule requirements is to pro-actively pursue effective bow wave and WIP metric values throughout the availability (NAVSEA 04X, 2012).

D. NAVSEA DEFINED SUCCESSFUL CNO AVAILABILITY

1. Overall Availability

The current standards used by NAVSEA 04 to define effective maintenance availabilities are based on schedule performance, cost performance, and overtime percentages.

Project Managers seek to complete availabilities that are (NAVSEA 04X, 2012):

- On or Ahead of Schedule (zero days late)
- Completed at 25% less cost (under budget) and have an average cost performance at or above 0.95.
- Completed with overtime levels not exceeding 5-10% for the availability

2. Short-term Metric Goals

Project leadership maintains a set of interim-availability metric goals, as well. These are generally viewed as the target metric values that project managers try to achieve during each week of the availability. The shipyards use a Likert scale to simplify their assessment of each metric, with a “1” being the lowest score (poor) and a “5” being the highest score (ideal) (NAVSEA 04X, 2012).

The following metric values translate to a Likert score of “5” according to current NAVSEA standards:

Metric	Value Corresponding to Likert Score of 5
Production Bow Wave	≤ 19%
Production Manning	80–84%
Total % Overtime Last Week	≤ 9%
Total Cost Performance	≥ 1.00
Total % Closed Work	≥ 75%
Key Event Performance/Float	≥ + 5 days (5 days of float)
Total Project WIP	≤ 94%
Total Throughput	≥ 95%
Total Average Cycle Time	≤ 7 days

Table 1. Interim Availability Metric Goals

Several of these metric goals require clarification. The Likert score for production manning decreases for values of production manning greater than 84 percent with a value equal to or greater than 100 percent receiving a Likert score of 1. In addition, it should be reiterated that the metric goal of seven days for average cycle time is the same for all availabilities regardless of availability length. Lastly, total cost performance is calculated and displayed as a decimal number.

E. SUMMARY

The current evaluation standards used by NAVSEA and the naval shipyards to track, analyze, and assess CNO availabilities are well documented within chapter 10A of the AIM-NG Process Manual. These standards will be utilized as points of reference while establishing analysis assumptions and benchmarks to be considered in this study.

IV. COMPLETED AVAILABILITY ANALYSIS

A. DATA COLLECTION

Analysis is conducted on data collected, processed, and provided by the Naval Systems Support Group at NAVSEA 04. The data whose analysis is discussed in this chapter is an assorted file of 85 completed CNO availabilities with the earliest availability completion date in 2006. The dates used in analyses are the actual completion dates of the availabilities. These data consist of submarine, aircraft-carrier, and surface ship CNO availabilities of varying length and scope. Thorough descriptions and procedures for calculations of the metrics provided in this data set are in chapter 10A of the AIM-NG process manual and have been discussed in Chapter III of this thesis. All four public naval shipyards are sufficiently represented in the data set; however, separate shipyards exhibit noticeably different maintenance profiles. These differences are primarily in the shipyard's ability or inability to support carrier maintenance and overhauls, as all shipyards were capable of performing requisite submarine maintenance work. The metrics are computed at the end of the availability. This data set is examined to assess the change in metric values over the period since the start of the lean initiative.

B. ANALYSIS APPROACH

Since the period the data are collected overlaps the start of the lean initiative, the metric values may depend on the time the availability starts and the shipyard performing the availability. The 85 CNO availabilities are partitioned by the time the availability completed; the shipyard conducting the availability; the length of the availability; and the lateness of the availability. The data are plotted to assess possible associations between the metrics computed at the end of the availability. Initial analysis scrutinized specific maintenance influences involving the executing shipyard, availability type and duration, and the point in time the availability was completed in relation to newly established LEAN practices (LEAN 2.0). In addition, dependent aspects like whether the availability finished early, on time, or late is considered while partitioning the data. Several metrics are transformed and scaled appropriately for the identification of possible associations during initial investigations. Transforming the data made spreads and ranges less extreme and associations more apparent. The strategic value of partitioning the data by availability completion times and seeking possible associations is to ensure that data sets being analyzed and compared are similar and not influenced by other dependent variables which are unaccounted for. In effect, the goal is to identify data that appear to be dependent upon the same variables and perform analysis which incorporates and accounts for those dependencies.

Several of the metrics provided by NSSG require weighting because their original calculations failed to account for availability length. Availability length is an important characteristic and must be considered in each metric. Many of the metrics compensate for the size or length of the availability by including the size of the work package in their calculations and are shown as percentages. However, it was obvious that days late, cycle time, and overtime percentage fail to adequately address availability size or length in their calculations. For example, in the case of days late, the difference between a six-month availability over-extending by 15 days is not properly differentiated from a 24-month availability missing its intended completion date by 15 days. When availabilities overrun their scheduled completion dates, longer availabilities are expected to miss their target date by a greater duration than shorter availabilities. Thus, using these metrics as originally provided in data analysis would result in findings dependent on a disregarded influence. A simple corrective action which would properly weight all of the metric data for days late, cycle time, and overtime percentage is to divide each availability's metric by that availability's originally planned duration (in days). So, in all analyses conducted on the 85 completed availabilities discussed in this chapter, days late, cycle time, and overtime percentage have been divided by the availability's planned duration to ensure they each account for the duration of the availabilities they represent.

C. GRAPHICAL ANALYSES

In this section the data are displayed graphically.

1. Graphical Displays of Metrics by Availability Length

In this subsection, graphs are presented of the project management performance metrics as they related to raw availability length. With access to both availability start and end dates, the total availability length in days can be calculated for each availability. Weekends and holidays are included in the total length of all availabilities to ensure consistency and analysis integrity. It is important to note that associations suggested in these plots are purely visual. The visual associations identified will be used to guide additional analysis and develop assumptions.

In Figure 3, the plot of total project WIP and availability length suggests that longer availabilities, especially those over 500 days, tend to have higher WIP levels. This observation will be important to consider when WIP is compared to other availability performance factors.

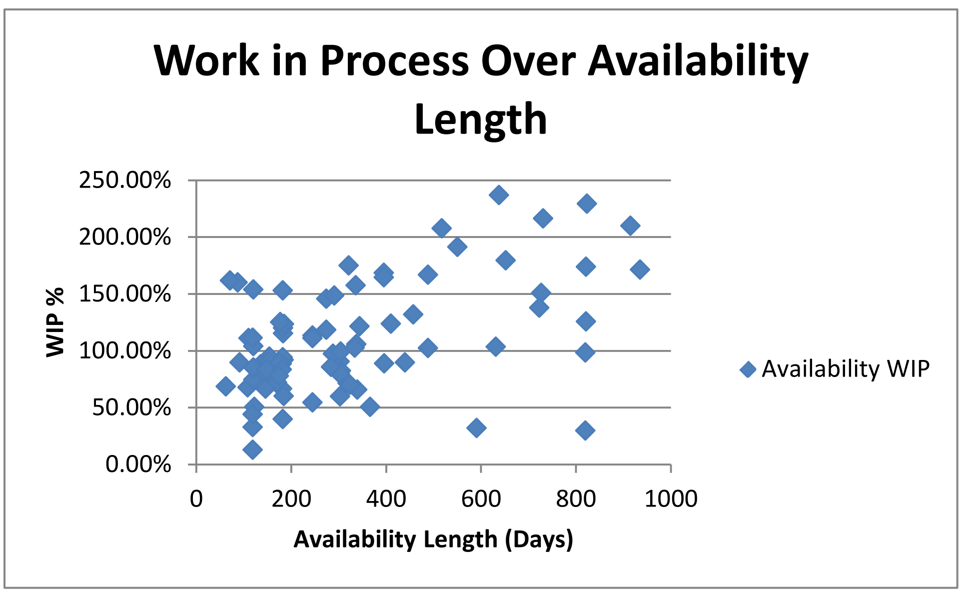

Figure 3. WIP over Increasing Availability Length

Figure 4 suggests that when longer availabilities run late they tend to do so with a larger number of days late than the number of days late for shorter availabilities. Longer availabilities are associated with days late having greater variability than those for shorter availabilities. This relationship was suspected prior to the start of analysis, and suggests that the days late or early for any availability should be adjusted for the length of the availability. One adjustment is to divide the days by length of the availability. Once adjusted for availability length, the days late or early for an availability can be used in seeking associations with other project management metrics.

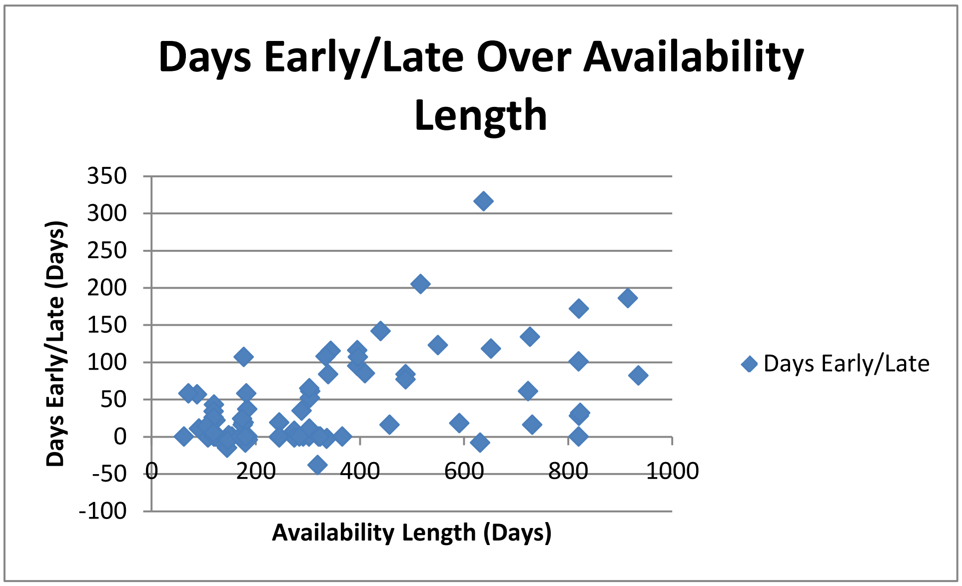

Figure 4. Days Early/Late over Availability Length

Figure 5 suggests that shorter availabilities have more variable overtime metrics at the end of the availability than longer availabilities. Conversations with a shipyard expert prior to commencing analysis suggested that the association displayed in Figure 5 is reasonable. According to that expert, shipyards tend to allocate more overtime to shorter availabilities as a standard business practice (J. Keller, personal communication, 2012). Even without this anecdote, it is well understood that availability length plays a key role in determining the percentage of overtime that project management can utilize in any given work package. Shorter availabilities can achieve far higher overtime percentages with far fewer days of overtime than longer availabilities.

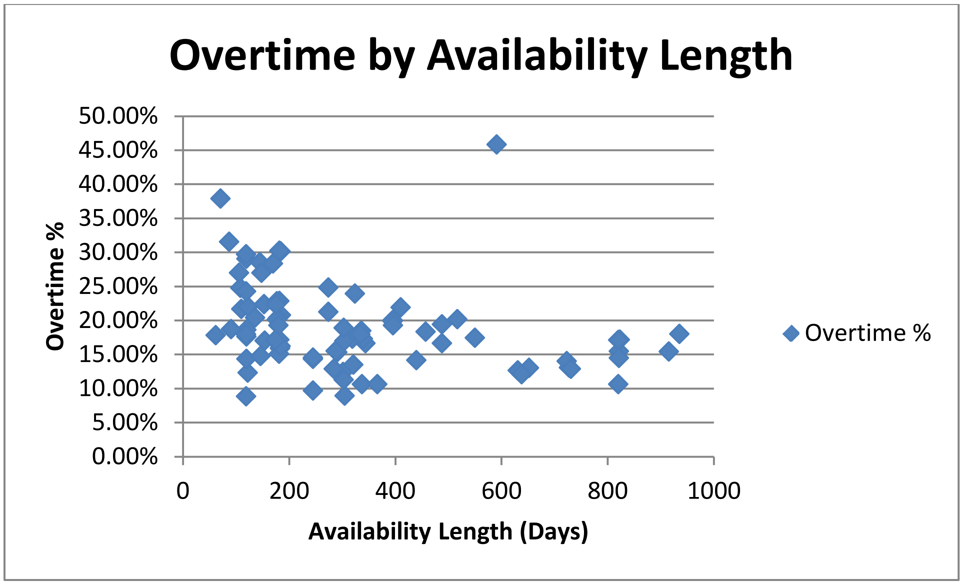

Figure 5. Overtime over Availability Length

Finally, Figure 6 displays cycle time computed at the end of the availability versus increasing availability length. The visual association presented in the plot suggests that the jobs executed during longer availabilities take longer to complete than jobs executed during shorter availabilities. Similar to days early and days late, cycle time is presented in terms of raw days. One modified metric is to divide the cycle time by the actual availability length. Figure 6 provides clear evidence that cycle time requires weighting prior to inclusion in analysis with other project management factors and metrics.

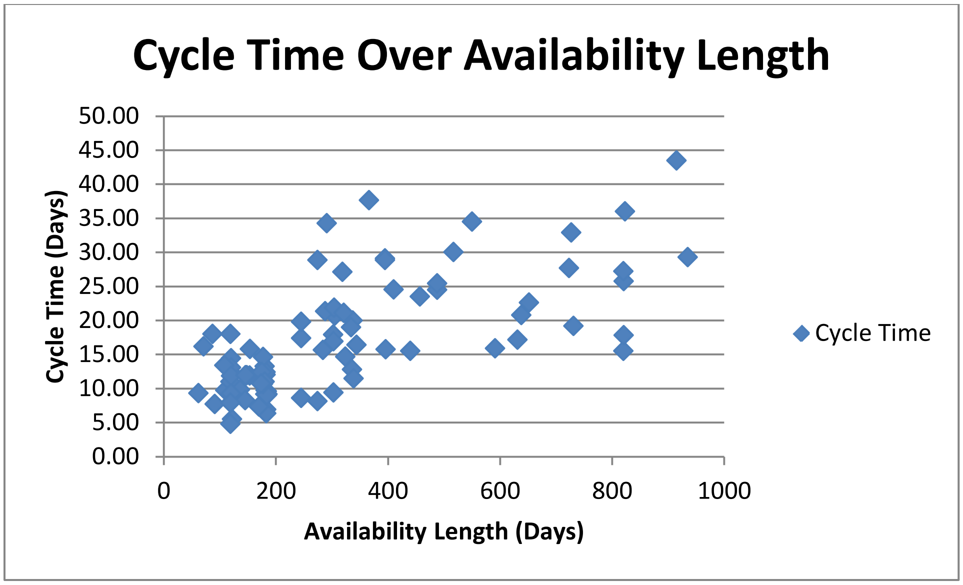

Figure 6. Cycle Time Over Availability Length

Additional plots of metrics over increasing availability length can be viewed in Appendix B.

2. Graphical Displays of Metrics over Time by Shipyard

In this subsection the associations between the actual time the availability ends and metrics computed at the end of the availability are considered. Figures 7–9 display end of availability metrics as a function of shipyard and scheduled time of availability completion.

First, however, plots which showed apparent visual associations were examined for potential indications of associations which would be found in the statistical analysis. Work in process, manning levels, closed work levels, and weighted cycle times all showed possible associations over time among the four naval shipyards.

While in Figure 7 none of the four shipyards show a distinctly different association over time, as a group they show that total project WIP computed at the end of availabilities tends to be smaller for availabilities whose actual completion time is later in the time period considered. Several higher WIPs occur for availabilities with actual completion later in the time period, but a much greater number of higher WIPs occur earlier in the period for PSNSY, NNSY, and PNSY. This visual association suggests that the change in availability management practices has had the desired effect of decreasing WIP in many cases. The dynamic nature of project WIP and its utility as a manageable project metric suggest that it would not provide useful information when computed at the end of the availability, but the plot may be suggestive to the contrary.

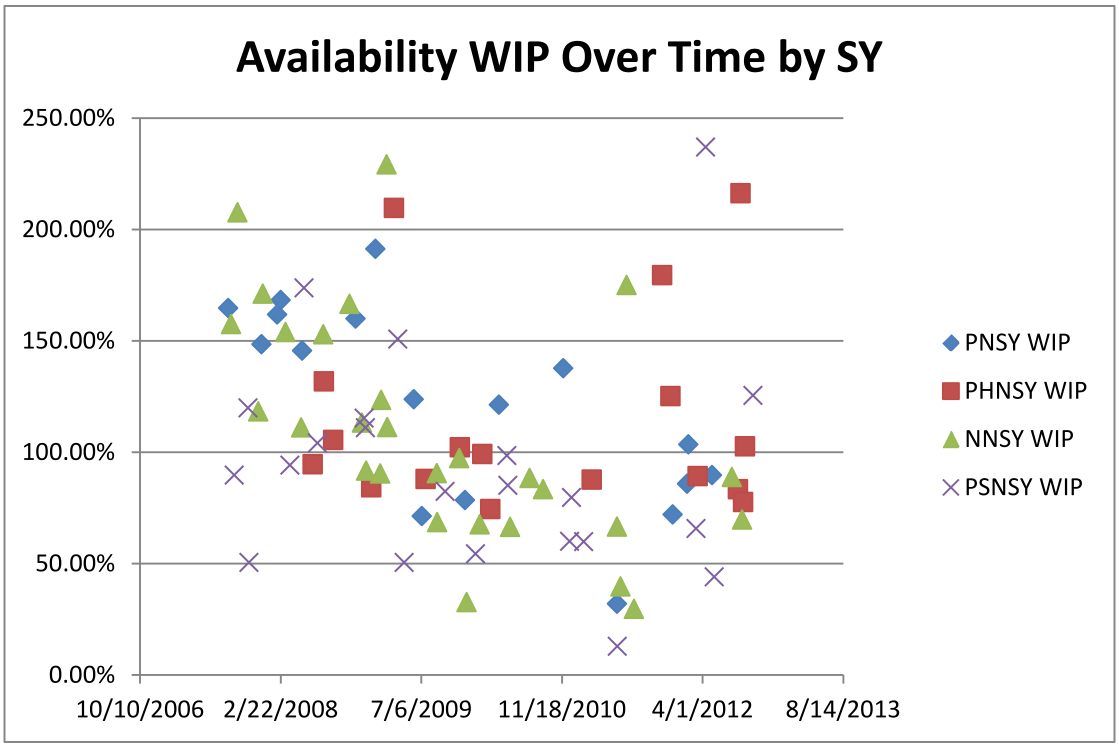

Figure 7. Shipyard Availability WIP over Time

Figure 8 displays the summary manning percentage computed at the end of the availability as a function of the actual completion time of the availability. In Figure 8, average manning percentages for availabilities tend to decrease approximately halfway through the time period. Shipyard manning apparently has similar associations with availability completion time. A decreasing level of manning would indicate that project efficiency and its related metrics are improving over time and that WIP levels are being actively managed through decreased manning within availabilities.

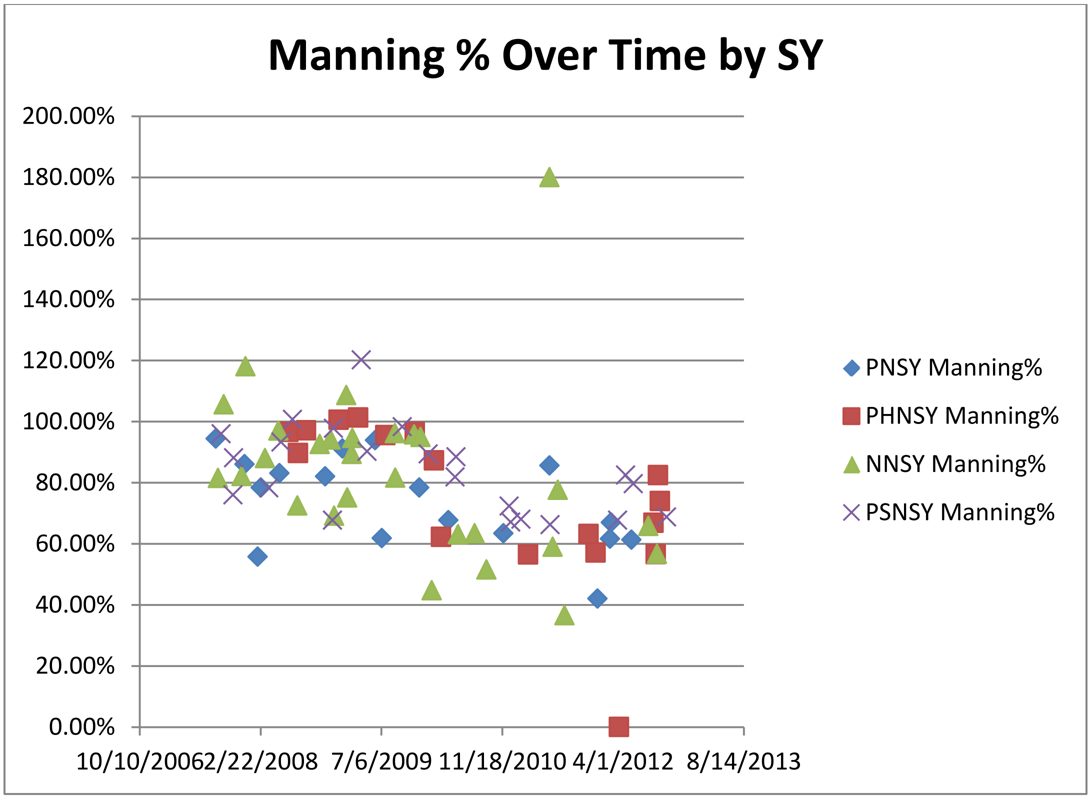

Figure 8. Shipyard Manning Percentages over Time

Figure 9 displays cycle time computed at the end of the availability divided by length of the availability and the actual completion time of the availability. The weighted cycle time is apparently smaller for availabilities with later actual completion times than those with earlier completion times. The shipyards appear to have somewhat similar graphs. This would suggest, again, that availability efficiency and possibly schedule performance are improving over time. Further analysis with the identified data set should determine the validity of this visual association.

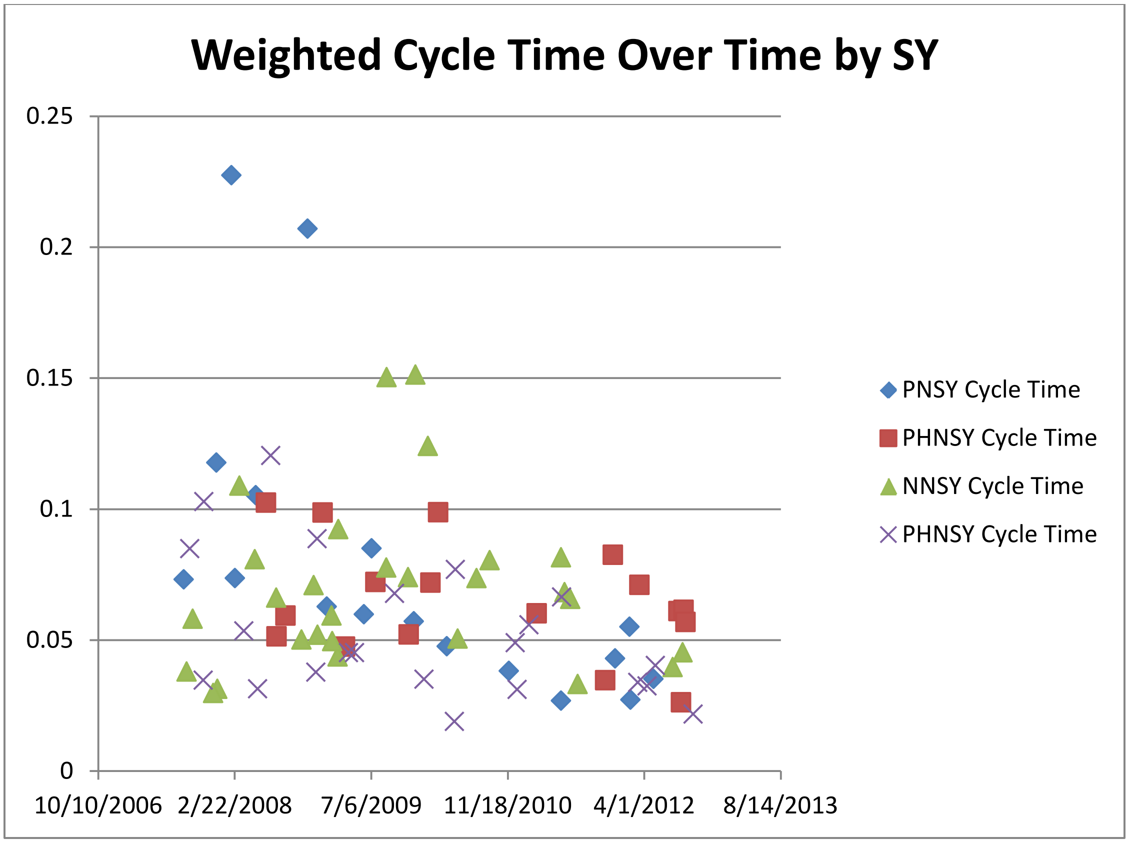

Figure 9. Shipyard Cycle Times (Weighted) over Time

To further identify and support associations between metrics, summary statistics and follow-on analysis is conducted on data from each shipyard. Table 2 displays the individual metric sample sizes, means, and standards errors for each shipyard. Additionally, to properly distinguish changes in metric statistics over time, these tables are divided into thirds. These thirds, or trimesters, represent progressing disjoint time periods over Lean Release 2.0's recognized time frame that are roughly equal in length. Availabilities are assigned to each trimester according to the actual availability completion date.

Calculations for summary statistics include (Hayter, 2007):

$$Sample\ Mean = \frac{\sum X_i}{n_i}\ for\ n_i\ samples\ where\ X_i\ is\ the\ i^{th}\ observation.$$

$$Standard\ Error(SE) = \sqrt{\frac{S}{n}}, where\ n = sample\ size\ and\ S = sample\ variance.$$

	Puget Sound Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	8	107.34%	11.43%	6	86.97%	13.55%	8	85.60%	22.80%
Manning	8	87.23%	3.94%	6	94.77%	5.04%	8	71.55%	2.05%
Overtime	8	16.76%	1.06%	6	12.30%	0.81%	8	16.56%	1.37%
Closed Work	8	70.28%	3.36%	6	81.67%	2.55%	8	89.19%	1.62%
Bow Wave	8	15.54%	2.06%	6	15.49%	2.87%	8	2.51%	17.07%
Throughput	8	90.32%	1.99%	6	91.68%	1.68%	8	92.16%	1.26%
Cost Performance	8	0.95125	1.57%	6	95.50%	2.78%	8	88.88%	2.72%

Table 2. Puget Sound Summary Statistics Across Disjoint Time Periods

Additionally, a scaled difference between the first and last period's sample means and standards errors was calculated to provide insight into whether there was a significantly large difference between the periods.

$$Scaled\ Difference\ Between\ Earliest\ and\ Latest\ Periods = \frac{(Avg_{latest} - Avg_{earliest})}{\sqrt{SE_{latest}{}^2 + SE_{earliest}{}^2}}$$

where

$$Avg_{latest} = Average\ Value\ from\ third\ trimester$$
$$Avg_{earliest} = Average\ Value\ from\ first\ trimester$$
$$SE_{latest} = Standard\ Error\ from\ third\ trimester$$
$$SE_{earliest} = Standard\ Error\ from\ first\ trimester$$

The calculation divides the difference in the sample averages of the first and third time period by an estimate of the variance of the difference between the sample averages. The denominator in scaled difference equation is the sum of the squares of the standard errors. Assuming the difference of the sample means is normally distributed with a mean of zero and the standard deviations are known, it is very unlikely that the absolute difference is greater than three standard deviations (Hayter, 2007). Thus, metrics with a scaled difference greater than 300 percent indicate a stronger association.

Puget Sound Naval Shipyard exhibits large scaled average differences between the first and third time periods averages for manning levels and closed work percentages (see Table 3). It is reasonable to assume that metrics for different availabilities are independent. However, they may not be identically distributed. While the summary statistics reveal no simple increasing or decreasing trend in the sample means for each period for manning levels, there is an increasing trend over each period for closed work. That association and the large scaled difference value suggest that closed work has indeed increased over time at Puget Sound Naval Shipyard.

Puget Sound Naval Shipyard		
Metric	**Scaled Difference Between the Average Value in Last Period and Earliest Period**	**Unusually Large Difference?**
Work in Process	-85.24%	No
Manning	-353.04%	Yes
Overtime	-11.55%	No
Closed Work	506.95%	Yes
Bow Wave	-75.78%	No
Throughput	78.12%	No
Cost Performance	-198.85%	No

Table 3. Scaled Difference Statistics at Puget Sound

At Norfolk Naval Shipyard two metrics emerge as having unusually large scaled average differences. The mean WIP levels show a gradually decreasing association over the three time periods (see Table 4). In Table 5, the scaled difference for WIP is very close to the 300 percent threshold for inclusion as a viable association; so for the purposes of this study it is identified as a significant metric of interest at Norfolk Naval Shipyard. The closed work metric produced a unusually large scaled average difference between the first and third period, but there is no obvious simple trend in the means over the three time periods. The sample averages computed for cost performance at Norfolk appear to decrease over the three time periods, however the low scaled average difference between the first and last period indicate that the perceived trend could be accounted for by data variability.

	Norfolk Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	10	144.44%	10.53%	12	95.79%	13.29%	6	78.30%	19.39%
Manning	10	90.09%	4.45%	12	79.94%	5.59%	6	79.29%	19.06%
Overtime	10	20.34%	1.84%	12	19.32%	1.68%	6	19.80%	2.34%
Closed Work	10	71.03%	2.13%	12	64.36%	3.45%	6	88.65%	3.11%
Bow Wave	10	21.94%	4.98%	12	25.63%	3.71%	6	-97.09%	128.79%
Throughput	10	84.40%	2.91%	12	75.47%	2.34%	6	92.16%	3.05%
Cost Performance	10	92.10%	2.65%	12	91.00%	2.38%	6	85.67%	2.76%

Table 4. Norfolk Summary Statistics across Disjoint Time Periods

Norfolk Naval Shipyard		
Metric	Scaled Difference Between the Average Value in Last Period and Earliest Period	Unusually Large Difference?
Work in Process	-299.75%	Maybe
Manning	-55.18%	No
Overtime	-18.14%	No
Closed Work	467.44%	Yes
Bow Wave	-92.35%	No
Throughput	184.08%	No
Cost Performance	-168.05%	No

Table 5. Scaled Difference Statistics at Norfolk

At Pearl Harbor, sample means in Table 6 indicate the possibility of trends existing for WIP, closed work, and throughput. WIP and closed work averages appear to be increasing, while throughput may show a decreasing association over time.

	Pearl Harbor Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	4	104.07%	8.86%	5	114.75%	21.68%	8	120.21%	16.88%
Manning	4	96.05%	1.97%	5	88.64%	6.23%	8	97.17%	30.00%
Overtime	4	16.98%	2.06%	5	17.41%	0.74%	8	18.19%	1.24%
Closed Work	4	64.45%	2.30%	5	64.11%	4.19%	8	80.44%	3.32%
Bow Wave	4	8.66%	3.25%	5	25.09%	1.19%	8	-5.03%	18.16%
Throughput	4	89.75%	0.82%	5	80.54%	1.22%	8	81.80%	1.20%
Cost Performance	4	88.00%	2.67%	5	84.40%	2.38%	8	92.59%	2.26%

Table 6. Pearl Harbor Summary Statistics Across Disjoint Time Periods

In Table 7, the scaled average difference calculation over the time frame discredits the notion that there may be a genuine increasing WIP association over time. However, it supports the increasing association over time in closed work and the decreasing association over time in throughput.

Pearl Harbor Naval Shipyard		
Metric	**Scaled Difference Between the Average Value in Last Period and Earliest Period**	**Unusually Large Difference?**
Work in Process	84.66%	No
Manning	3.73%	No
Overtime	50.32%	No
Closed Work	395.90%	Yes
Bow Wave	-74.21%	No
Throughput	-546.99%	Yes
Cost Performance	131.22%	No

Table 7. Scaled Difference Statistics at Pearl Harbor

Finally, Portsmouth's summary statistics in Table 8 indicate a decreasing association over time in WIP, a decreasing association in manning, and an increasing association in closed work. The successive sample averages for WIP appear very pronounced.

	Portsmouth Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Work in Process	6	158.15%	3.39%	5	117.26%	19.13%	6	86.80%	13.01%
Manning	6	79.99%	4.85%	5	78.59%	5.63%	6	63.48%	5.19%
Overtime	6	24.91%	3.13%	5	20.36%	2.01%	6	21.31%	5.00%
Closed Work	6	61.72%	3.94%	5	66.77%	4.36%	6	82.80%	4.11%
Bow Wave	6	41.29%	4.35%	5	38.18%	3.18%	6	4.49%	31.85%
Throughput	6	82.67%	2.92%	5	76.52%	4.47%	6	87.77%	2.82%
Cost Performance	6	89.83%	1.86%	5	93.00%	6.10%	6	90.50%	3.20%

Table 8. Portsmouth Summary Statistics Across Disjoint Time Periods

In Table 9, the pronounced decreasing association in WIP over time at Portsmouth Naval Shipyard is confirmed by a high-scaled average difference value. The manning association is not supported by a large scaled average difference value. However the scaled average difference between early and last period mean closed work is unusually large.

Portsmouth Naval Shipyard		
Metric	Scaled Difference Between the Average Value in Last Period and Earliest Period	Unusually Large Difference?
Work in Process	-530.70%	Yes
Manning	-232.42%	No
Overtime	-61.03%	No
Closed Work	370.25%	Yes
Bow Wave	-114.48%	No
Throughput	125.63%	No
Cost Performance	18.10%	No

Table 9. Scaled Difference Statistics at Portsmouth

Summary statistics for the metrics which are divided by availability length are presented in Tables 10 through 13. These tables display both the weighted and unweighted sample average for days late, days early or on time, and cycle time over the three disjoint time intervals. The availabilities are assigned to the time intervals based on their scheduled completion times. For the purposes of assessment and analysis, only the weighted values are considered.

	Puget Sound Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	2	0.0775	0.0307	2	0.1922	0.0055	8	0.1837	0.0527
Days Late	2	19.5000	6.0104	2	97.5000	25.8094	8	85.0000	36.1732
Days Early/On-time - Weighted	6	-0.0018	0.0011	4	0.0000	0.0000	N/A	N/A	N/A
Days Early/On-time	6	-0.3333	0.1925	4	0.0000	0.0000	N/A	N/A	N/A
Cycle Time - Weighted	8	0.0693	0.0113	6	0.0482	0.0079	8	0.0413	0.0049
Cycle Time	8	14.7922	3.7029	6	15.4035	3.7842	8	12.2588	1.8483

Table 10. Weighted Metric Summary Statistics for PSNSY

	Norfolk Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	7	0.1855	0.0512	6	0.0859	0.0396	3	0.2374	0.0480
Days Late	7	67.2857	23.7733	6	18.3333	6.3011	3	88.6667	12.5992
Days Early/On-time - Weighted	3	-0.0056	0.0014	6	-0.0136	0.0064	3	-0.0114	0.0093
Days Early/On-time	3	-1.6667	0.5443	6	-2.3333	1.1706	3	-1.6667	1.3608
Cycle Time - Weighted	10	0.0586	0.0073	12	0.0856	0.0103	6	0.0556	0.0071
Cycle Time	10	17.6631	2.3912	12	15.1949	2.1068	6	17.1783	2.2031

Table 11. Weighted Metric Summary Statistics for NNSY

	Pearl Harbor Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	2	0.1069	0.0509	4	0.1372	0.0358	7	0.2096	0.0692
Days Late	2	19.0000	2.1213	4	79.2500	33.6440	7	58.2857	17.3237
Days Early/On-time - Weighted	2	-0.0030	0.0021	1	-0.0515	0.0000	1	0.0000	0.0000
Days Early/On-time	2	-1.0000	0.7071	1	-7.0000	0.0000	1	0.0000	0.0000
Cycle Time - Weighted	4	0.0780	0.0114	5	0.0685	0.0081	8	0.0568	0.0061
Cycle Time	4	17.8575	2.1428	5	22.4969	5.3809	8	15.0263	1.5370

Table 12. Weighted Metric Summary Statistics for PHNSY

	Portsmouth Naval Shipyard								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	5	0.4071	0.1285	4	0.2124	0.0443	2	0.1766	0.1033
Days Late	5	66.8000	16.5491	4	96.0000	12.3390	2	80.0000	43.8406
Days Early/On-time - Weighted	1	0.0000	0.0000	2	-0.1113	0.0055	3	-0.0042	0.0035
Days Early/On-time	1	0.0000	0.0000	2	-26.5000	8.1317	3	-2.6667	2.1773
Cycle Time - Weighted	6	0.1341	0.0250	6	0.0584	0.0059	5	0.0375	0.0047
Cycle Time	6	25.8800	2.6637	6	23.0784	3.4702	5	14.2980	1.5851

Table 13. Weighted Metric Summary Statistics for PNSY

The performance of each metric varied depending on the shipyard being considered. However, three out of the four shipyards show summary statistics which support the decreasing trend of average weighted cycle time over the disjoint time intervals. This suggests that regardless of the length of the availability, cycle time may be generally decreasing since the beginning of Lean Release 2.0 initiatives. Norfolk was the only shipyard to not show a decreasing trend in sample weighted cycle time averages over time, but did decrease from the second disjoint subinterval to the third disjoint subinterval. Pearl Harbor shows an increasing average weighted days late trend over the time period while Portsmouth availabilities appeared to show a decreasing weighted days late average over time. Overall, the shipyards display different trends in the average weighted days late over the three time periods. This could be a reflection on the effectiveness of management policies at the beginning of the lean initiative.

Availability lateness across the four public shipyards is further investigated using binomial probabilities. We assume that each availability in a shipyard is late or early/on time independent of the other availabilities; this assumption is supported by the results of Caprio and Leszczynski (2012). The fraction of availabilities that completed early or on time with scheduled completion date in the earliest times period is computed for each shipyard. This fraction is the estimate of the probability an availability completes early or on time. The number of availabilities with scheduled completion date in the last period to complete early or on time is modeled as having a binomial distribution with number of trials equal to the number of availabilities completed during the last period and probability of success equal to this estimate. Table 14 displays the estimated expected number of early or on time availabilities in the last period based on the number of availabilities with scheduled completion times in the last period; the observed number of early or on time availabilities in the last period; and the fraction of availabilities that are early or on time from earlier time periods. This approach allows researchers to assess whether actual values obtained are reasonably summarized by the estimated probability of early or on time performance obtained for earlier time periods.

The formula used to calculate these binomial probabilities is (Hayter, 2007):

$$P(k\ successes\ in\ n\ trials) = \binom{n}{k} p^k q^{n-k}$$

where,

n = the number of trials

k = the number of successes; k = 0,1,…, n

n-k = number of failures

p = probability of success of one trial

q = 1-p = probability of failure of one trial

Table 14 displays the estimated expected number of availabilities that complete early or on time for the model. Estimated probabilities that the number of early or on time availabilities is greater than or equal to (respectively less than or equal to) the number observed in the last time period are also displayed. Probabilities close to 0 or 1 suggest that there is a low probability that the observed value would occur based on past performance at that shipyard and the Binomial model (Hayter, 2007).

In Table 14, Puget Sound stands out among the other shipyards. Puget Sound has zero availabilities finish early or on time in the final time interval, while the predicted expected value for that time interval is 5.71 early/on time availabilities based on earlier performance. This observation suggests that Puget Sound has an unusually low number of early and on time availabilities in the final time period and it would appear that schedule performance there has changed in the final time period. The low number for Pearl Harbor is not that unusual.

Computed Values	**PSNSY**	**NNSY**	**PHNSY**	**PNSY**
Total Availabilities Finishing in 3rd time period	8	6	8	5
Number of Early/On-time Availabilities Finishing in the 3rd time period	0	3	1	3
Fraction of Availabilities in the 1st period that are early/on-time	0.75	0.3	0.5	0.16667
Fraction of Availabilities in the first 2 periods that are early/on-time	0.71429	0.4091	0.3333	0.2500
Expected # of Early/On-time Availabilities using fraction from 1st period	6.0000	1.8	4	0.83333
Expected # of Early/On-time Availabilities using fraction from first 2 periods	5.7143	2.4545	2.6667	1.25
Probability (number of early/on time avails in 3rd period is ≤ observed) for Binomial model with number of trials equal to the number of avails ending in the 3rd period and probability of success equal to the fraction of avails completed early/on time in the first 2 periods	0.0000	0.8080	0.1951	0.9844
Probability (number of early/on time time avails ≥ observed number in the 3rd period) for Binomial model with number of trials equal to the number of avails ending in the 3rd period and probability of success equal to the fraction of avails completed early/on time in the first 2 periods	1.0000	0.4745	0.9610	0.1035

Table 14. Binomial Probabilities of Availability Lateness Across Shipyard

3. Metric Trends over Time as a Function of Availability Length

In an earlier section, availability metrics were compared according to length based on the raw length in days. In this section, availabilities are categorized into short, medium, and long availabilities based on both raw availability length and availability type. Short availabilities are defined as lasting less than six months, medium-length availabilities last between six and 12 months, and long availabilities last longer than 12 months. Performance metrics are graphically displayed as a function of the scheduled availability completion time.

Figure 10 displays manning percentages as a function of the actual completion availability time. Aside from the apparent decreasing trend over time discussed earlier, there is no apparent difference in manning percentages between short, medium, and longer availabilities. The plot suggests that manning percentages have similar decreasing trends over time for the three categories of availability length.

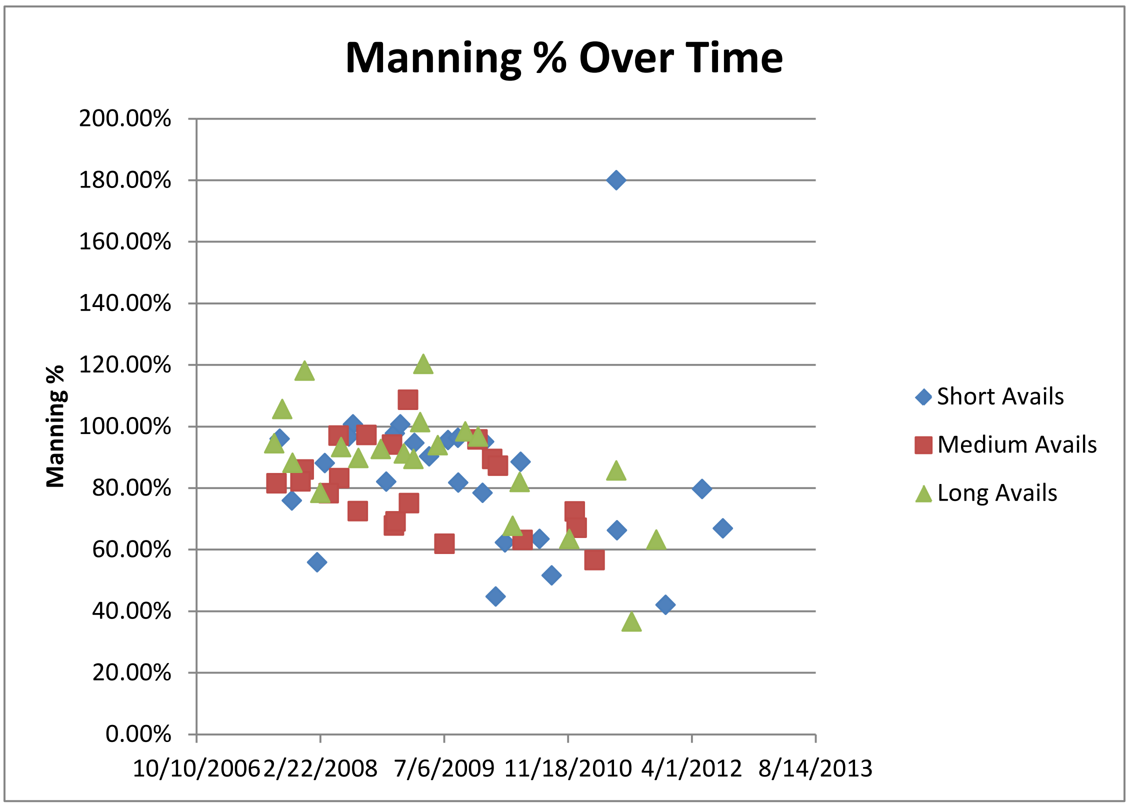

Figure 10. Availability Manning Percentages over Time by Defined Length

In Figure 11, shorter availabilities clearly have lower closed work levels in the first half of the Lean Release time frame. However, by the second half, closed work values for shorter availabilities have increased to the point that there is no distinguishable difference between the ships in each of the three availability length categories. There is no distinguishable difference between medium and long availabilities throughout the time frame covered in the plot. Also, the earlier recognized association between actual availability completion time and increasing closed work is again apparent.

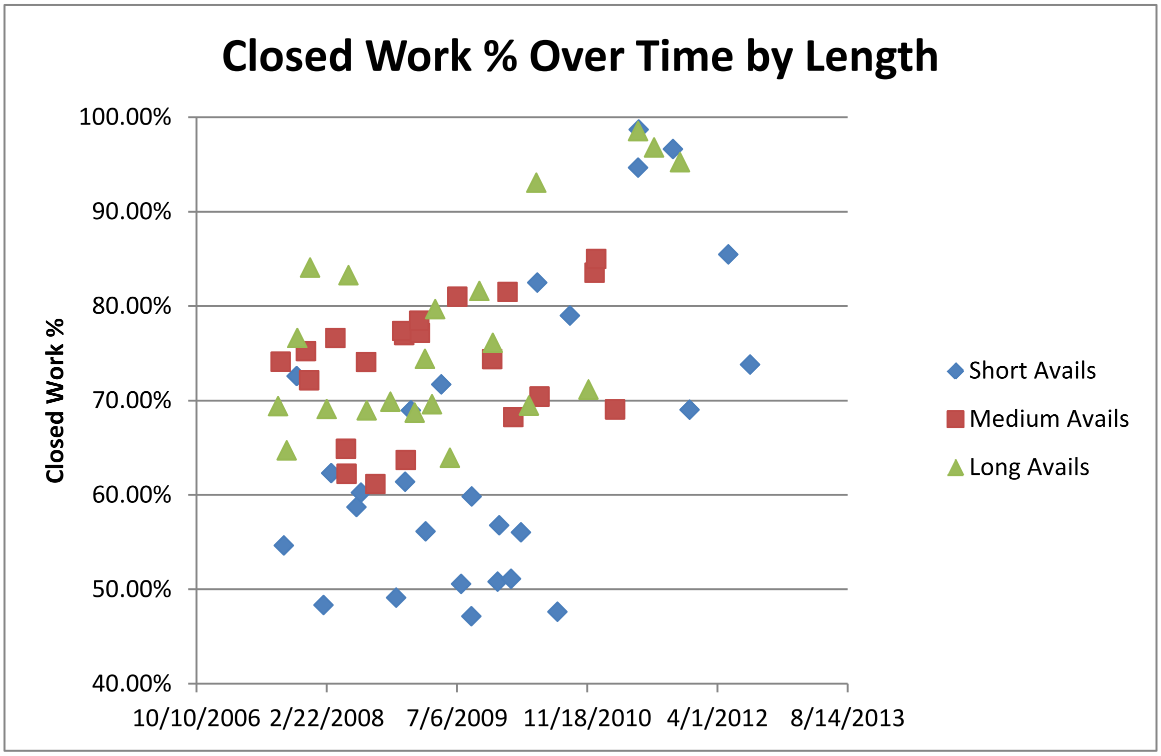

Figure 11. Availability Closed Work Percentage over Time by Defined Length

Recall that Figure 6 suggests that cycle time tends to increase as a function of the actual availability completion time. In Figure 12, this trend is further supported as shorter availabilities tend to produce shorter raw cycle times. Figure 13 displays the cycle times divided by the actual length of the availability. In Figure 13, higher weighted cycle times from shorter availabilities are clearly present during the first half of the time period. This suggests that, after considering availability length, shorter availabilities exhibited poor cycle time performance in relation to medium and longer availabilities. The weighted cycle times are less variable over time. However, this trend may be an artifact of the division of cycle time by actual availability length.

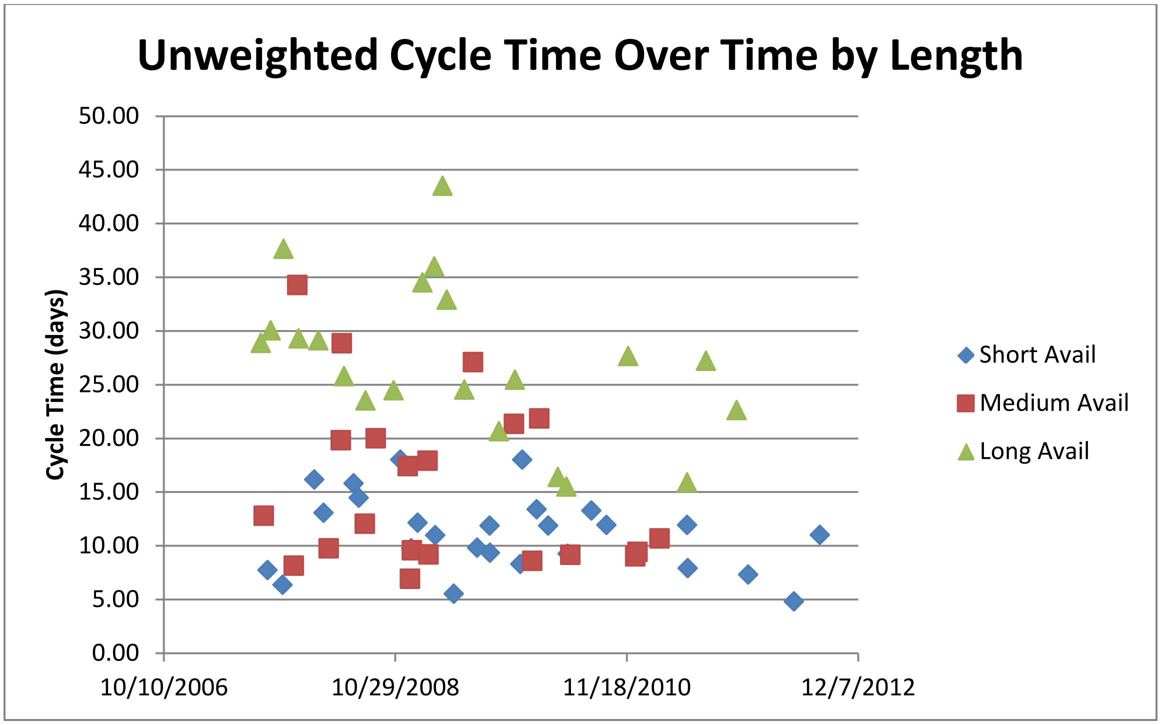

Figure 12. Availability Unweighted Cycle Time Over Time by Defined Length

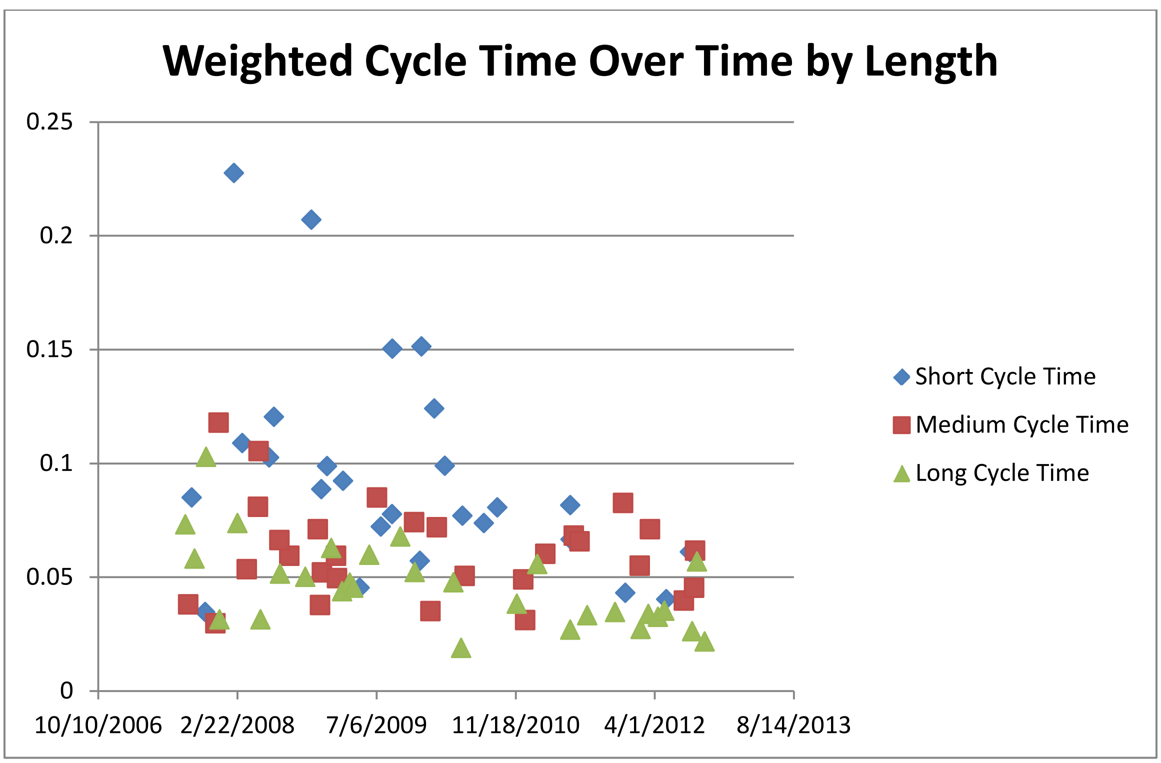

Figure 13. Availability Weighted Cycle Time Over Time by Defined Length

In the final plot, Figure 14, WIP's decreasing trend with actual availability completion time is again supported. In addition, longer availabilities exhibit larger WIP levels earlier in the time period compared to medium and shorter availabilities. Even toward the end of the time period, the WIP levels of longer availabilities still tend to be larger than those for short and medium availabilities. However, no distinguishable difference existed between short and medium availabilities.

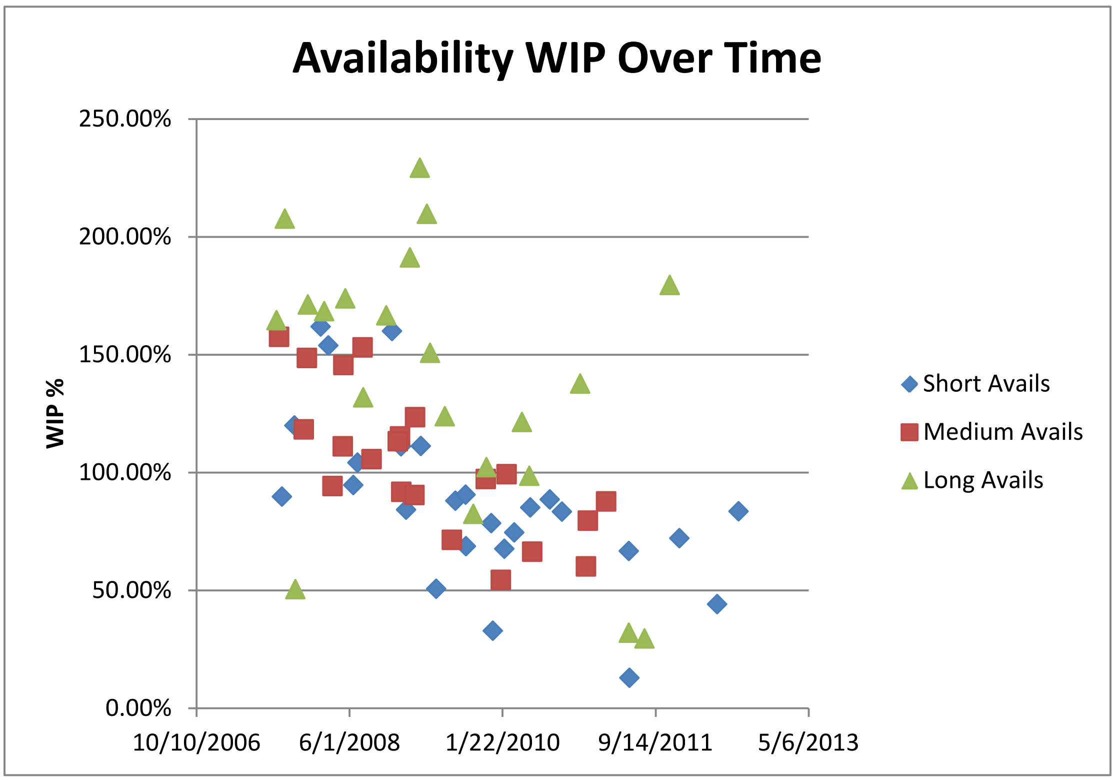

Figure 14. Availability WIP Over Time by Defined Length

Each of the three categories of availabilities (short, medium, and long) are assigned to three time periods based on actual completion times. Sample averages and associated standard errors for those metrics are displayed in Tables 15, 17, 19, 21, 22, and 23.

The summary statistics for shorter availabilities are displayed in Table 15. Sample averages for WIP display a decreasing trend over the three time periods, while average cost performance displays smaller increasing trends over the same time periods (see Table 15).

	Short Avails (< 6 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	9	119.93%	9.73%	12	76.61%	5.61%	5	55.85%	11.18%
Manning	9	88.18%	4.67%	12	78.53%	5.10%	5	86.95%	21.51%
Overtime	9	23.60%	2.37%	12	20.34%	1.81%	6	21.92%	2.02%
Closed Work	9	59.59%	2.55%	12	59.10%	3.34%	6	86.37%	4.67%
Bow Wave	9	22.06%	5.95%	12	25.78%	3.66%	6	-144.01%	121.82%
Throughput	9	88.73%	1.74%	12	76.19%	2.55%	5	90.08%	3.96%
Cost Performance	9	90.22%	1.45%	12	92.25%	2.99%	6	96.12%	2.78%

Table 15. Short Availability Summary Statistics across Disjoint Time Periods

Table 16 displays the difference in sample average metrics for the first period and the third period divided by the square root of the sum of the squares of the estimated standard errors. The results suggest that short availabilities have smaller average work in process (respectively larger average closed work) for availabilities with scheduled completion time in the last period than those with completion time in the first time period.

Short Avails (< 6 months)		
Metric	Scaled Difference Between the Average Value in Last Period and Earliest Period	Unusually Large Difference?
Work in Process	-432.36%	Yes
Manning	-5.59%	No
Overtime	-53.95%	No
Closed Work	503.30%	Yes
Bow Wave	-136.16%	No
Throughput	31.21%	No
Cost Performance	188.17%	No

Table 16. Scaled Difference Statistics for Short Availabilities

Table 17 displays the sample average and standard error for the metrics in the three time periods for medium length availabilities. Average WIP and cost performance metrics for medium-length availabilities appear to be decreasing over time, while average closed work again appears to be increasing. For average WIP, the trend seems to be strongest between the first and second time periods, as the second and third period sample averages are very similar.

	Medium Avails (6 months < X < 12 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	11	123.11%	6.85%	7	86.10%	8.23%	11	88.99%	10.19%
Manning	11	82.63%	3.00%	7	83.02%	6.04%	11	88.81%	22.24%
Overtime	11	18.23%	1.77%	7	16.08%	0.92%	11	19.75%	1.43%
Closed Work	11	70.76%	1.84%	7	75.87%	1.79%	11	82.32%	2.49%
Bow Wave	11	26.61%	3.03%	7	22.97%	4.63%	11	9.03%	14.38%
Throughput	11	91.09%	1.05%	7	83.15%	2.62%	11	85.01%	1.85%
Cost Performance	11	96.91%	1.88%	7	93.71%	3.14%	11	87.73%	1.89%

Table 17. Medium-Length Availability Summary Statistics across Disjoint Time Periods

Table 18 displays the difference between the metric sample mean in the first and last time period divided by the square root of the sum of the squares of the standard errors. Average WIP and cost performance (respectively average closed work) are smaller (respectively larger) for availabilities with scheduled completion times in the last period compared to those in the first period.

Medium Avails (6 months < X < 12 months)		
Metric	Scaled Difference Between the Average Value in Last Period and Earliest Period	Unusually Large Difference?
Work in Process	-277.89%	No
Manning	27.54%	No
Overtime	66.80%	No
Closed Work	373.38%	Yes
Bow Wave	-119.63%	No
Throughput	-285.82%	No
Cost Performance	-344.36%	Yes

Table 18. Scaled Difference Statistics for Medium-Length Availabilities

Table 19 displays sample averages and associated standard errors for long availabilities. Table 20 displays the difference in the metric sample averages between the last and first period divided by the square root of the sum of the squares of the standard errors. Sample averages in Table 19 suggest associations involving decreasing manning levels while closed work and throughput increase over time for longer availabilities. In addition, average WIP also appears to be decreasing over time within the same data set. This interesting dynamic among longer availabilities would suggest that shipyard project leadership is getting better project performance with less manning. Table 20 discounts the WIP association, but supports the other associations. Based on these calculations, project leadership can argue with better certainty that project performance efficiency is improving over time for longer availabilities.

	Longer Avails (> 12 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Work in Process	8	154.33%	15.43%	10	144.70%	14.97%	11	112.85%	20.31%
Manning	8	95.04%	3.96%	10	90.40%	4.94%	11	66.49%	3.77%
Overtime	8	17.74%	1.08%	10	15.18%	1.11%	11	17.15%	2.81%
Closed Work	8	73.25%	2.38%	10	74.77%	2.51%	11	89.76%	1.60%
Bow Wave	8	16.86%	6.20%	10	28.67%	3.27%	11	13.54%	18.67%
Throughput	8	77.63%	2.57%	10	83.44%	3.18%	11	90.55%	1.74%
Cost Performance	8	86.88%	1.62%	10	87.40%	2.42%	11	88.18%	2.17%

Table 19. Long Availability Summary Statistics across Disjoint Time Periods

Longer Avails (> 12 months)		
Metric	**Scaled Difference Between the Average Value in Last Period and Earliest Period**	**Unusually Large Difference?**
Work in Process	-162.63%	No
Manning	-522.17%	Yes
Overtime	-19.60%	No
Closed Work	575.70%	Yes
Bow Wave	-16.88%	No
Throughput	416.29%	Yes
Cost Performance	48.01%	No

Table 20. Scaled Difference Statistics for Long Availabilities

In Tables 21 through 23, the average weighted days late for late availabilities is increasing over time over the three time periods and for all three availability length classifications. In addition, the average weighted cycle time displays a decreasing trend over the 3 time periods.

Follow-on analysis was conducted pertaining to average days late in the third time period for short, medium, and long availabilities. It is assumed that an availability is early/on time or late independent of the other availabilities. The fraction of availabilities that are early/on time during the first period is the estimate of the probability that an availability is early/on time. The number of availabilities that are early/on time in the last period is modeled as a binomial random variable with the number of trials equal to the number of availabilities with actual completion times in the last period and the probability of success equal to the estimated probability.

	Short Avails (< 6 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Days Late - Weighted	8	0.2663	0.1049	7	0.0523	0.0366	5	0.0785	0.0380
Days Late	8	23.8750	8.3917	7	6.2857	4.3411	5	9.0000	4.4362
Days Early/On-time - Weighted	1	-0.0055	0.0000	5	-0.0430	0.0157	1	-0.0342	0.0000
Days Early/On-time	1	-1.0000	0.0000	5	-6.4000	2.3255	1	-5.0000	0.0000
Cycle Time - Weighted	9	0.1192	0.0191	12	0.0917	0.0094	5	0.0585	0.0069
Cycle Time	9	12.6031	1.2519	12	11.1246	0.8617	5	8.5860	1.1565

Table 21. Weighted Metric Summary Statistics for Short Availabilities

	Medium Avails (6 months < X < 12 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	4	0.0783	0.0377	3	0.0994	0.0401	8	0.1965	0.0651
Days Late	4	16.2500	6.7950	3	29.3333	12.2414	8	42.8750	14.1812
Days Early/On-time - Weighted	7	-0.0040	0.0011	4	-0.0352	0.0246	3	0.0000	0.0000
Days Early/On-time	7	-1.1429	0.3741	4	-10.5000	7.9804	3	0.0000	0.0000
Cycle Time - Weighted	11	0.0647	0.0080	7	0.0608	0.0060	11	0.0572	0.0043
Cycle Time	11	16.3210	2.5410	7	16.4476	2.6207	11	13.3127	1.0144

Table 22. Weighted Metric Summary Statistics for Medium Length Availabilities

	Longer Avails (> 12 months)								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	Sample Size	Mean	SE	Sample Size	Mean	SE	Sample Size	Mean	SE
Days Late - Weighted	7	0.1799	0.0483	9	0.1815	0.0265	10	0.2170	0.0429
Days Late	7	89.4286	21.8266	9	97.1111	14.7618	10	114.0000	25.9411
Days Early/On-time - Weighted	1	0.0000	0.0000	1	0.0000	0.0000	1	-0.0127	0.0000
Days Early/On-time	1	0.0000	0.0000	1	0.0000	0.0000	1	-8.0000	0.0000
Cycle Time - Weighted	8	0.0590	0.0079	10	0.0484	0.0042	11	0.0349	0.0033
Cycle Time	8	28.5900	1.4564	10	27.7086	2.7067	11	18.4973	1.1816

Table 23. Weighted Metric Summary Statistics for Long Availabilities

Table 24 displays the results of further analysis conducted on the short, medium-length, and longer availabilities. The observed numbers of early/on time availabilities for short and long availabilities in the third period are not unusual for the binomial model. Thus there is no statistically apparent change in the probability an availability completes early or on time between the first and third period for short and long availabilities. However, medium-length availabilities displayed unusual performance in the final trimester. According to performance in the previous two trimesters, medium-length availabilities should have produced around an average seven early and on time availabilities out of the total 11 medium-length availabilities. Instead, only three availabilities out of the 11 finished early or on time. According to the binomial probabilities calculated, there was only a 2.4 percent chance of three or less availabilities completing early or on time. This extremely low percentage suggests that medium-length availabilities experienced a change in schedule performance during this final time period.

Computed Values	Short Avails	Medium Avails	Long Avails
Total Availabilities Finishing in 3rd time period	5	11	11
Number of Early/On-time Availabilities Finishing in the 3rd time period	1	3	1
Fraction of Availabilities in the 1st period that are early/on-time	0.111	0.64	0.125
Fraction of Availabilities in the first 2 periods that are early/on-time	0.286	0.611	0.111
Expected # of Early/On-time Availabilities using fraction from 1st period	0.556	7	1.375
Expected # of Early/On-time Availabilities using fraction from first 2 periods	1.429	6.722	1.222
Probability (number of early/on time avails in 3rd period is ≤ observed) for Binomial model with number of trials equal to the number of avails ending in the 3rd period and probability of success equal to the fraction of avails completed early/on time in the first 2 periods	0.558	0.024	0.650
Probability (number of early/on time time avails ≥ observed number in the 3rd period) for Binomial model with number of trials equal to the number of avails ending in the 3rd period and probability of success equal to the fraction of avails completed early/on time in the first 2 periods	0.814	0.995	0.726

Table 24. Binomial Probabilities of Availability Lateness Across Shipyard

4. Associations by Availability Lateness

In continuing with a thorough inspection of schedule performance, Section 4 will further analyze early, on time, and late availabilities for trends and associations within the metrics.

The plot displayed in Figure 15 suggests that even after weighting the “days early/late” metrics to availability length, late availabilities have an average number of days late which is larger than the average number of days early for early or on time availabilities. This suggests that when commencing an availability, schedule estimations and expectations are generally going to underestimate the amount of time it takes to complete an availability. Very rarely will an on time or early availability finish exceptionally ahead of schedule; while it is reasonable to expect that a late availability will be at risk of large schedule delays.

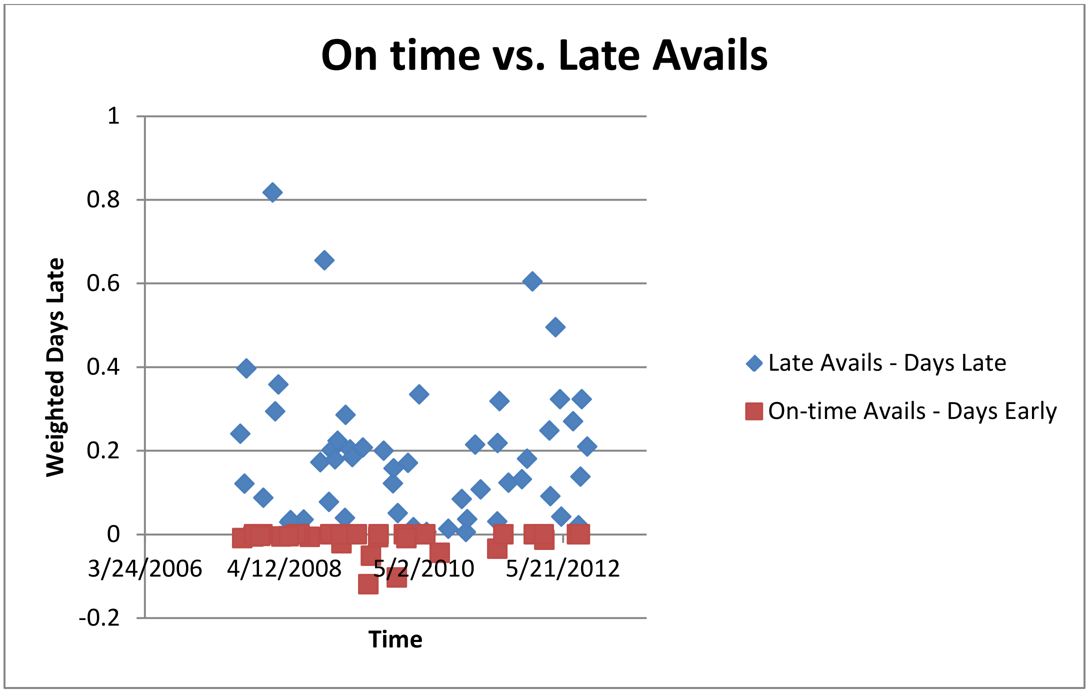

Figure 15. Availability Days Late/Early Over Time

In Figure 16, weighted cycle times for both late and early/on time availabilities are displayed over the time period. There is no distinguishable difference in cycle times of late and early/on time availabilities, but there is more variability for availabilities with actual early/on time completion times. The partitioned data sets overlay each other for the duration of the time period and do not indicate differing associations with time.

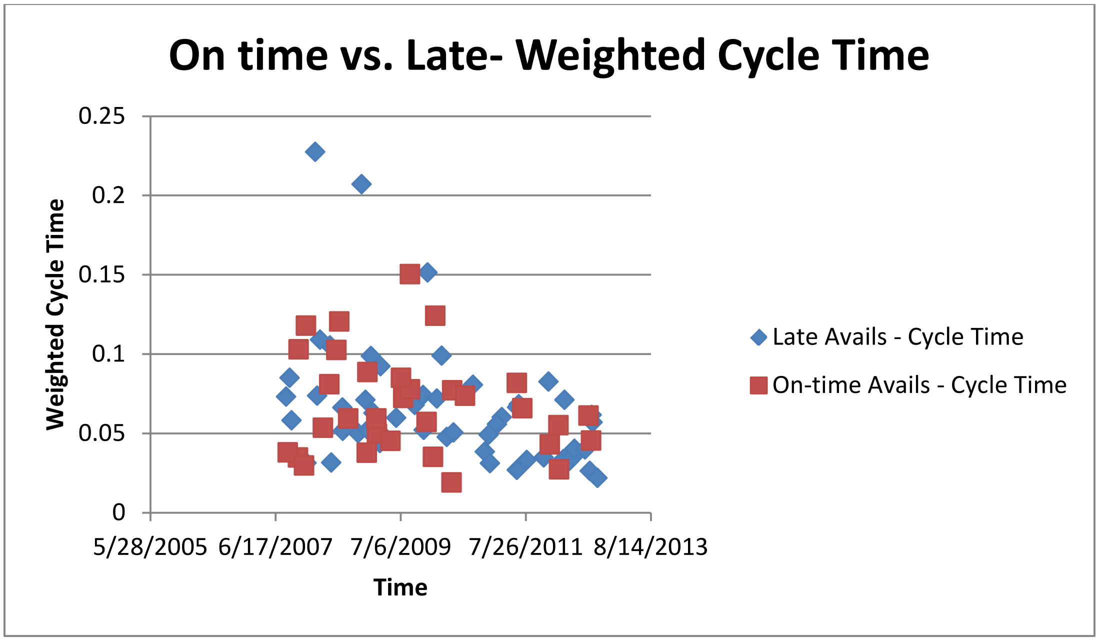

Figure 16. Weighted Cycle Times for Late and On time Availabilities Over Time

Overall, the graphical plots and visual associations of late and early/on time availabilities exposed very little in terms of insight into availability metric relationships. Thus, the raw data from availabilities with actual completion times on one of three disjoint time periods is considered for further analysis.

Tables 25 and 26 display summary data and analysis over the disjoint time intervals for on time and early availabilities. Of interest in Table 25 is that average manning percentages again show a decreasing trend over the three time intervals and average closed work percentages have a large spike upward in the final time interval.

	On-Time/Early Availabilities								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Work in Process	12	110.91%	7.46%	13	81.22%	5.14%	7	93.79%	13.29%
Manning	12	87.43%	2.91%	13	81.21%	4.52%	7	78.83%	16.08%
Overtime	12	16.01%	1.10%	13	18.20%	1.41%	7	17.90%	2.16%
Closed Work	12	69.21%	2.01%	13	67.11%	4.34%	7	81.83%	3.07%
Bow Wave	12	17.92%	3.04%	13	23.43%	4.04%	7	-87.87%	110.06%
Throughput	12	91.05%	1.38%	13	82.29%	2.71%	7	86.93%	2.51%
Cost Performance	12	96.00%	1.41%	13	96.62%	2.21%	7	92.96%	3.02%

Table 25. On-Time/Early Availability Summary Statistics across Disjoint Time Periods

Applying the previously used "scaled average difference" analysis calculations and approach, it is evident from Table 26 that the apparent trend in average manning percentages is not widely since there is not an usually large scaled average difference between the earliest and latest periods. However, average closed work percentage is apparently increasing since the scaled average difference is unusually large.

On-Time/Early Availabilities		
Metric	**Scaled Difference Between the Average Value in Last Period and Earliest Period**	**Unusually Large Difference?**
Work in Process	-112.33%	No
Manning	-52.63%	No
Overtime	77.97%	No
Closed Work	343.92%	Yes
Bow Wave	-96.08%	No
Throughput	-143.84%	No
Cost Performance	-91.21%	No

Table 26. Scaled Difference Statistics for On-Time/Early Availabilities

Summary data for late availabilities are displayed across the three-time interval in Table 27. For late availabilities, average WIP and average manning percentages exhibit a decreasing trend while average closed work again displays a sharp increase in the third trimester. Scaled average difference calculations in Table 28 would support assertions of a change in average WIP and average closed work, but not average manning percentages.

	Late Availabilities								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Work in Process	16	146.08%	8.44%	16	119.58%	12.96%	20	92.14%	13.07%
Manning	16	88.36%	3.62%	16	85.73%	4.48%	20	79.56%	12.60%
Overtime	16	22.66%	1.56%	16	16.99%	1.33%	21	19.63%	1.65%
Closed Work	16	66.88%	2.52%	16	69.72%	1.97%	21	87.54%	1.86%
Bow Wave	16	25.69%	4.48%	16	28.27%	2.21%	21	-0.03%	13.57%
Throughput	16	83.06%	1.98%	16	78.81%	2.27%	20	88.65%	1.61%
Cost Performance	16	88.81%	1.57%	16	86.31%	1.95%	21	88.62%	1.54%

Table 27. Late Availability Summary Statistics across Disjoint Time Periods

Late Availabilities		
Metric	**Scaled Difference Between the Average Value in Last Period and Earliest Period**	**Unusually Large Difference?**
Work in Process	-346.70%	Yes
Manning	-67.13%	No
Overtime	-133.44%	No
Closed Work	659.62%	Yes
Bow Wave	-179.98%	No
Throughput	219.05%	Yes
Cost Performance	-8.64%	No

Table 28. Scaled Difference Statistics for Late Availabilities

	On-Time/Early Availabilities								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Days On-Time/Early - Weighted	12	-0.003	0.001	13	-0.027	0.011	7	-0.007	0.005
Days On-Time/Early	12	-0.750	0.267	13	-5.692	2.856	7	-1.857	1.150
Cycle Time - Weighted	12	0.072	0.009	13	0.071	0.009	7	0.054	0.006
Cycle Time	12	16.303	2.839	13	12.232	1.486	7	14.117	1.576

Table 29. Weighted Metric Summary Statistics for On time/Early Availabilities

	Late Availabilities								
	8/20/2007 - 1/10/2009			1/11/2009 - 11/23/2010			11/24/2010 - 9/28/2012		
Metric	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**	**Sample Size**	**Mean**	**SE**
Days Late - Weighted	16	0.231	0.056	15	0.148	0.026	22	0.192	0.032
Days Late	16	55.125	12.743	15	63.000	14.048	22	72.227	15.393
Cycle Time - Weighted	16	0.087	0.014	15	0.070	0.007	21	0.046	0.004
Cycle Time	16	20.378	1.925	15	22.603	2.570	21	15.318	1.286

Table 30. Weighted Metric Summary Statistics for Late Availabilities

D. SUMMARY

This section presents results concerning associations and trends identified in end-of-availability metric data for 85 separate CNO availabilities obtained from graphical displays and summary statistics.

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V. INTERIM AVAILABILITY ANALYSIS

A. ANALYSIS APPROACH

A second data set compiled and provided by NSSG includes weekly-interim metric data for the nine performance metrics being investigated in this study for a number of availabilities.

The data set contains data concerning many availabilities. However, the completeness of each availability's data varied significantly. This chapter reports on the analysis of five pairs of availabilities. In each pair, one availability is selected as the example of desirable availability performance and the other is selected to represent the availability exhibiting poor performance. Five total pairs represent the aggregate data: a longer carrier availability, a longer submarine availability, a submarine availability executed in a non-carrier yard, a short submarine availability, and a short carrier availability. The actual completion time of the availability is not considered in determining the pairs; the availability shipyard is also not considered.

Criteria for selecting each pair of availabilities included considering schedule performance and cost performance. A desirably performing availability is defined as being completed with a cost performance which meets a minimum threshold of 0.94 and schedule performance demonstrating minimal lateness relative to availability length. Most of these availabilities are completed on time or early. A poorly performing availability is defined as being completed with a cost performance which meets a maximum threshold of 0.83 and schedule performance demonstrating a high degree of lateness relative to availability length. However, it should be noted that the maximum threshold for cost performance could not be met on the shorter submarine availability due to data set constraints. In addition, selections attempted to maintain close parity in availability length, but several pairs exhibit wider ranges in length due to data set limitations. Overall, the five pairs of availabilities represent the best possible given the data set provided. Despite the relatively significant difference in size between REA and

TMN for the longer carrier availability, both availabilities involve a Planned Incremental Availability which entails the same type of work packages.

Table 31displays each availability pair considered in this analysis.

Weekly Interim Performance Data - Analysis Data Set Profile							
Avail Code	**Hull/Ship**	**Type of CNO Availability**	**Length**	**Days Late**	**CP**	**Avail Start**	**Avail Complete**
REA	CVN-76	PIA	7 months	1	1.00	11/18/09	5/19/10
TMN	CVN-75	DPIA	17 months	107	0.78	2/28/11	7/15/12
C22	SSN-722	EOH	25 months	16	1	7/29/10	8/14/12
900	SSN-700	PIRA	15 months	115	0.77	1/5/09	4/9/10
951	SSN-751	EOH	21 months	-8	0.94	5/29/10	2/11/12
174	SSN-774	DSRA	19 months	142	0.82	10/1/10	5/5/12
167	SSN-767	DSRA	4 months	-15	1.16	8/1/09	12/9/09
MNA	SSGN-727	MMP	4 months	14	0.88	6/15/11	10/13/11
73B	CVN-73	SRA	5 months	0	0.98	1/11/10	5/11/10
EHW	CVN-69	PIA	8 months	58	0.83	10/18/10	6/15/11

Table 31. Interim Availability Data Set Profile

B. RESULTS

Table 32 displays the sample average and associated standard errors of the weekly metrics computed over roughly the first 30 percent of the availabilities. The number of weeks that comprise the first 30 percent of the availability is computed for each availability in the pair. The smaller of the two numbers is used as the number of weeks in the first 30 percent of the availability. The bow wave average percentage during the first 30 percent of the availability in the "good" availability is smaller than the bow wave average in the "bad" availability for all five pairs. Desirable availabilities have an average weekly bow wave percentage between 22 and 38.8 percent. Undesirable availabilities have an average weekly bow wave percentage between 27.8 and 55.9 percent. Four of the five desirable availabilities have an average throughput greater than or equal to that of the poor availability in the pair. Only the desirable "Short Sub" availability has average throughput less than that of its poor availability. Also both desirable and undesirable "Long Sub" availabilities maintained a 74.3 percent weekly throughput average.

	First 30% of Weekly Availability Data for Selected Interim Availabilities									
	Longer CVN		Longer Sub		Sub-Only SY		Short Sub		Short CVN	
Metric	Good (REA)	Poor (TMN)	Good (C22)	Poor (900)	Good (951)	Poor (174)	Good (167)	Poor (MNA)	Good (73B)	Poor (EHW)
Bow Wave %	27.1 (21.4)	55.9 (1.93)	33.3 (1.97)	34.5 (2.27)	22 (2.24)	27.8 (2.73)	38.8 (2.38)	51.2 (3.02)	32.9 (3.01)	45.3 (3.06)
Manning %	65 (23.9)	37.8 (3.23)	66.9 (3.06)	89.3 (8.96)	77 (2.49)	68.8 (3.49)	64.2 (3.70)	66.6 (5.07)	85.3 (18.89)	50.2 (2.36)
Overtime %	15.5 (2.02)	21.4 (.56)	6.5 (.63)	13 (1.45)	10 (.54)	11.7 (.60)	29.4 (2.74)	10.3 (2.36)	19.4 (1.82)	20.4 (1.81)
Cost Performance	113.3 (2.67)	103.2 (.51)	103.8 (.66)	93 (.24)	102 (.50)	100.3 (.50)	85 (1.67)	98.5 (2.05)	102.9 (.595)	96.1 (.26)
Closed Work %	68.2 (1.41)	54.1 (3.73)	60.4 (3.50)	56 (.64)	70 (3.05)	67 (3.46)	38.8 (1.17)	49.7 (8.28)	82.3 (1.69)	46.5 (6.45)
Float (days)	2.1 (.9)	(-) 6 (3.14)	56.6 (2.05)	(-) 5.07 (1.61)	5.6 (.942)	7.5 (1.83)	0.17 (1.35)	5.7 (.211)	1.29 (1.96)	(-)9.9 (2.85)
WIP	106.8 (23.4)	99.2 (5.53)	77.1 (4.92)	166.8 (4.71)	109 (4.72)	84.7 (3.06)	93.9 (7.87)	50.2 (5.37)	77.8 (3.89)	77.6 (3.38)
Throughput	58.6 (1.32)	48 (7.81)	74.3 (1.98)	74.3 (2.18)	93 (.53)	60.6 (1.77)	42.7 (3.35)	51.5 (4.75)	81.2 (1.43)	50.9 (13.6)
Cycle Time (days)	6.7 (20.6)	18.8 (1.74)	9 (1.26)	16.3 (.38)	8.7 (.357)	9.4 (.194)	15.4 (1.95)	8.5 (.884)	15.2 (1.40)	8.7 (.098)

Table 32. Summary Metric Averages for Interim Availability Pairs

Finally, average WIP is larger in the desirable availability of four of the five availability pairs. One of those four pairs displayed a negligible difference in the average WIP between the desirable and undesirable availability. While based on a small sample size, we expect that WIP may be a metric with stronger associations at the interim availability level.

Figure 17 displays weekly bow waves for the first 30 percent of the availability for the longer carrier availability pair; also displayed are the average bow waves over the first 30 percent of the availability. The bow wave for the desirable availability is generally decreasing over time. Note that the desirable availability bow wave is larger than that of the poor availability during one week. These average trend lines show that weekly bow waves for desirable availabilities tend to remain lower than those for undesirable availabilities over the first third of the availability. Figure 19 displays a similar plot of weekly bow waves for the longer sub availability pairing. Thus, there is the suggestion that summary metrics to monitor availability performance should include metrics for more than one week. Additional plots of the bow wave metric for other availability pairs show a similar relationship and can be found in Appendix E.

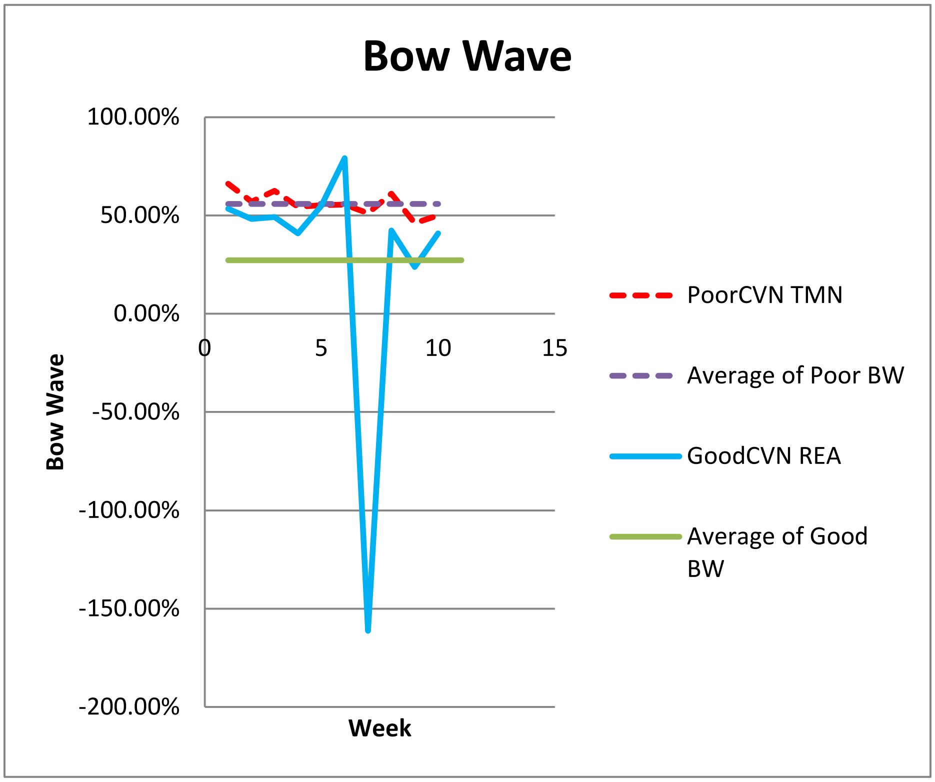

Figure 17. Longer CVN Bow Wave Values over First Third of Availability

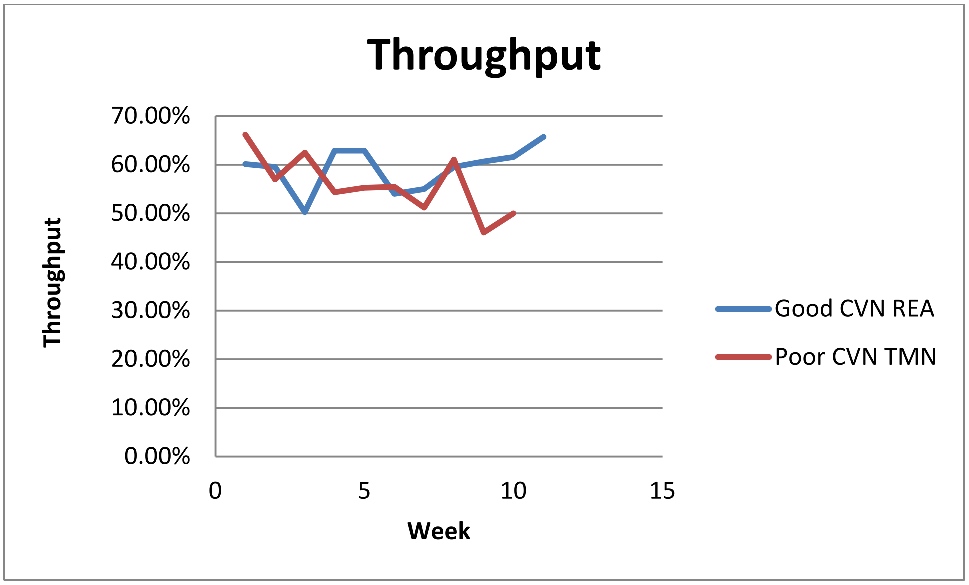

Figure 18. Longer CVN Throughput Values over First Third of Availability

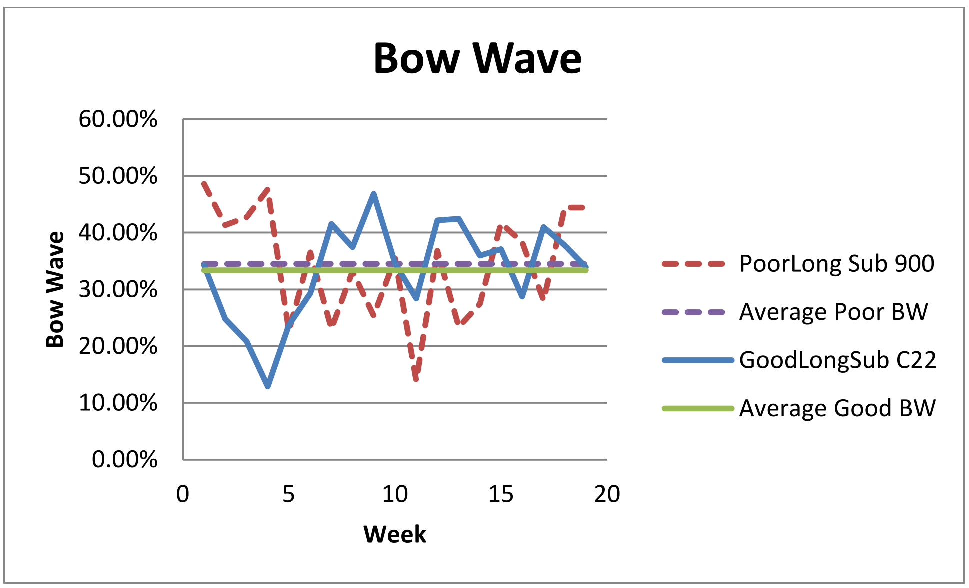

Figure 19. Long Sub Bow Wave Values over First Third of Availability

C. DISCUSSION

The data analysis described above initiates the exploration of good and poor availability classification and their associated summary metrics computed with weekly metrics obtained early during an availability. Average bow wave over a period of weeks appears to have the most consistent association with good and poor availability performance. Individual weekly bow wave does not seem to have predictive ability. However, five pairs of availabilities are simply not a large enough sample size to draw conclusive results. Further, the members of the pairs are chosen without regard to the scheduled start and completion availability times. Differences in the metrics of the members of a pair could be influenced by changes in availability management during the time period. It is important to compare availabilities of the same type with roughly similar scheduled start and completion times. Finally, earlier results suggest that availability length influences some metrics. Longer availabilities tend to have larger work package sizes. Thus, the size of the work package underway must always be considered. The value of this initial data analysis is in identifying several metrics with promise for future analysis and possible associations across availabilities. In closing, a far more exhaustive approach to analyzing interim availability metric data is required to draw stronger findings. The analyses should as much as possible compare availabilities of the same type with comparable start and scheduled completion times.

VI. CONCLUSION AND FUTURE STUDIES

A. SUMMARY OF INVESTIGATION

This study explores and analyzes recent project management efforts during CNO maintenance availabilities with respect to specific performance metric data collected since the origination of new lean management efforts. These new lean management techniques are outline in NAVSEA's LEAN Release 2.0 Recommendation.

Researched topics and subject areas include:

- Trends in availability metric performance over the time period covering LEAN Release (2006–2013).
- Trends specific to an availability's overall work in process in relation to other key performance metrics.
- Influence of availability length on availability performance and trends among performance metrics for those maintenance availabilities.
- Significance and implication of weighting specified metrics to account for availability length when the original metric fails to provide proper weighting.
- Comparison of metrics for early and on time availabilities to those from late availabilities.
- Inspection of weekly CNO availability data collected during the first 30 percent of the availability length and its association with the overall assessment of availability performance.

B. SUMMARY OF RESULTS

This thesis presents results of analysis of two data sets. One data set consists of average metrics computed at the completion of each of 85 availabilities. The other consists of weekly metrics for some availabilities. Both data sets are comprised of availabilities whose actual completion times occur during the period since the start of the lean initiative. It is expected that the effects of the lean initiative will appear gradually over time and may be influenced by availability type. In summarizing the results of the two separate data sets, it is noted that treatment and partitioning of the data can be just as important as identifying and analyzing metric trends. It is important to account for the time of the start or actual completion of an availability from the beginning of the lean initiative and the availability type in the data analysis. These two factors were found to be important in numerous trends and associations. Furthermore, the findings of each data set are considered separately as they concern metrics computed at different times during the availability.

1. Analysis of End-of-Availability Metric Averages for 85 Completed Availabilities

The stronger findings extracted from average completed availability metric data compiled at the end of the availability include:

- Various performance metrics show either an increasing or decreasing association over time since the initiation of the lean initiative.
  - Average WIP, average cycle times, and average manning levels tend to decrease
  - Average closed work percentages tend to increase
  - There is no statistically apparent change in the likelihood that an availability will complete early or on time.
  - There is no apparent trend in average bow wave
- Days late, float, and cycle time are influenced by availability length
- When days late is divided by availability length, there are no associations across shipyards or actual availability completion times.
- There is no association between average manning levels and availability length.
- Shorter availabilities with actual completion dates closer to the beginning of the lean initiative tend to have lower average closed work percentages than medium and longer availabilities. There is no difference in the average closed work for short, medium, and longer availabilities for actual completion dates at the end of the considered time period.
- Longer availabilities have higher average WIP values than short and medium length availabilities.
- Short and medium length availabilities utilize higher average over-time percentages than longer availabilities.

2. Analysis of Weekly Metric Data from First Third of Availabilities

The noticeable findings drawn from interim weekly availability metric data include:

- During the first third of an availability, desirable availabilities may have lower average bow wave percentages than undesirable availabilities, and average has a range of 20–40 percent bow wave.
- During the first third of an availability, desirable availabilities may maintain higher average throughput percentages than undesirable availabilities.

C. CONCLUSIONS AND RECOMMENDATIONS

Specific research questions concerning shipyard project management metrics critical to stakeholder needs and understanding that are addressed in this study include:

1. Are performance-based metrics for CNO availabilities improving over time and since the inception of NAVSEA's Lean Release?
2. Have process improvement initiatives improved cost and schedule performance in CNO availabilities?
3. Are performance metrics comparable for availabilities of different lengths?
4. How do specific performance metrics impact and influence other performance metrics?
5. What level of granularity within the evaluation spectrum is ideal for specific metrics so that data analysis reveals useful associations pertaining to that metric?

The data consist of availabilities whose actual completion times occur during the period since the start of the lean initiative. Thus, it is expected that the effects of the lean initiative will appear gradually over time as changes in average metrics. The following list summarizes the major findings of this thesis:

1. Average Performance Metrics Show Trends over the Time Period

Average availability WIP, average cycle times, and average manning tend to be smaller for availabilities with actual completion dates later in the time period than those with actual completion dates closer to the start of the lean initiative. Average closed work percentages tend to be larger for availabilities with actual completion times later in the time period considered than those with actual completion times closer to the start of the lean initiative. All of these trends indicate a general improvement in availability proficiency and efficiency over time. Further studies could single out individual metrics and conduct exhaustive research to further support or discount these assertions.

2. The Work in Process Metric and Bow Wave Metric May Have Little Relevancy at the Overall Availability Level

At the overall availability level, not a single plot or data partition identified a trend or association pertaining to these important project management metrics. The reasoning may very well be that these metrics are important for the weekly management of the availability but not for overall assessment. Weekly data is readily available at shipyards and supporting commands.

3. Availability Length Needs to be Accounted for When Analyzing Days Late and Cycle Time

The calculation of days late and cycle time do not account for the size of the availability they represent. There are apparent associations between days late and cycle time with scheduled availability length. Modified metrics are computed by dividing days late and cycle time by the actual availability length. With this weighting, follow-on analysis results in far more consistent and credible trends relating to days late and cycle time.

4. Average WIP, Average Days Late, Average Closed Work, Average Over Time, and Average Cycle Time Depend on Availability Length

The plots displayed in Chapter IV, Section 1 show strong evidence that these metrics are impacted by the length of the availability. As discussed above, we'd expect higher average days late and average cycle times for longer availabilities which further supports weighting those metrics. In addition, average WIP (respectively average overtime percentage) tends to increase (respectively decrease) with increasing availability length. Further investigations into the business practices and shipyard management approaches pertaining to longer CNO availabilities may provide insight into the cause of these trends.

5. Longer Availabilities Have Higher Average WIP Values Than Short and Medium Length Availabilities

As shown in Figure 13 of Chapter IV, Section 3, longer availabilities tend to have larger WIP levels than medium and short availabilities. This behavior also appears in the average WIP values computed for availabilities with actual completion times occurring in 3 disjoint time intervals from the start of the lean initiative displayed in Tables 15, 17, and 19. The relation of average WIP values and scheduled availability length is a strong candidate for further research if additional data sets can be obtained.

6. Short and Medium Length Availabilities Utilize Higher Over-Time Percentages Than Longer Availabilities

Another reoccurring theme is that overtime is less utilized in longer availabilities than it is in short and medium length availabilities. Further investigations into the business practices and shipyard management approaches may provide insight into the cause. We recommend a more thorough investigation into shipyard overtime policy prior to more data analysis efforts.

7. During the Initial Weeks of an Availability, Desirably Performing Availabilities Tend to Maintain Lower Bow Wave Percentages Than Undesirable Availabilities.

Of the five pairs of similar availabilities analyzed, all five of the desirable availabilities maintained lower average bow wave percentages during the first 30 percent of the availability than the undesirable availabilities. However, more research is needed to recommend metrics which forecast availability on time performance.

In closing, this research only initiates the wide-ranging effort that could be conducted pertaining to CNO availability performance metric analysis. Shipyards and supporting offices collect immense amounts of pertinent data, and if that data is collected and organized effectively, it is capable of driving valuable research. Follow-on efforts to understand how performance measurement and control data impact availability cost and schedule performance can only improve the decision-making abilities of shipyard and project leadership.

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APPENDIX A. GRAPHICAL DATA DISPLAYS

The following tables summarize the visual trends observed in availability metric performance over the time period and increasing WIP:

		Interim Metrics								
		WIP	Days Late	Manning	Overtime %	Closed Work	Bow Wave	Throughput	Cycle Time	Cost Performance
Data Sets	PSNSY	P(d)	P(i)	O(d)	N	O(i)	P(i)	P(i)	P(d)	P(d)
	NNSY	O(d)	N	O(d)	N	P(i)	N	P(i)	P(d)	N
	PHNSY	N	N	O(d)	N	O(i)	N	P(d)	P(d)	P(i)
	PNSY	O(d)	N	O(d)	N	O(i)	N	P(i)	O(d)	N
	Medium Length	P(d)	P(i)	P(d)	N	O(i)	P(d)	P(d)	P(d)	P(d)
	Short Length	O(d)	P(d)	P(d)	P(d)	O(i)	N	N	O(d)	P(i)
	Long Length	P(d)	N	O(d)	P(d)	O(i)	N	O(i)	O(d)	N
	On-Time	P(d)	N	P(d)	P(i)	O(i)	P(i)	P(d)	P(d)	P(d)
	Late	P(d)	N	O(d)	P(d)	O(i)	N	P(i)	P(d)	P(i)

Table 33. Performance Metric Trends over the Lean Release Time Period

N	Negligable
P	Possible
O	Obvious
(i)	increasing over time
(d)	decreasing over time
	Possible Association
	Stronger Association

Table 34. Legend for Time Period Table

		Interim Metrics							
		Days Late	Manning	Overtime %	Closed Work	Bow Wave	Throughput	Cycle Time	Cost Performance
Data Sets	PSNSY	P(i)	P(i)	P(d)	N	N	N	P(i)	P(d)
	NNSY	N	P(i)	N	P(d)	P(d)	N	O(i)	P(d)
	PHNSY	P(i)	P(d)	O(d)	O(i)	N	P(d)	P(i)	N
	PNSY	N	P(i)	N	O(d)	N	N	O(i)	P(d)
	Medium Length	N	P(d)	N	P(d)	N	P(i)	P(i)	N
	Short Length	P(i)	N	O(i)	O(d)	N	N	P(i)	P(d)
	Long Length	P(i)	N	N	P(d)	N	P(d)	P(i)	P(d)
	On-Time	P(i)	P(i)	P(d)	N	N	P(d)	P(i)	N
	Late	P(i)	P(i)	P(d)	N	N	N	P(i)	P(d)

Table 35. Performance Metric Trends over Increasing WIP

N	Negligable
P	Possible
O	Obvious
(i)	increasing with increasing WIP
(d)	decreasing with increasing WIP
	Possible Association
	Stronger Association

Table 36. Legend for Increasing WIP Table

APPENDIX B. ADDITIONAL AVAILABILITY LENGTH METRIC PLOTS

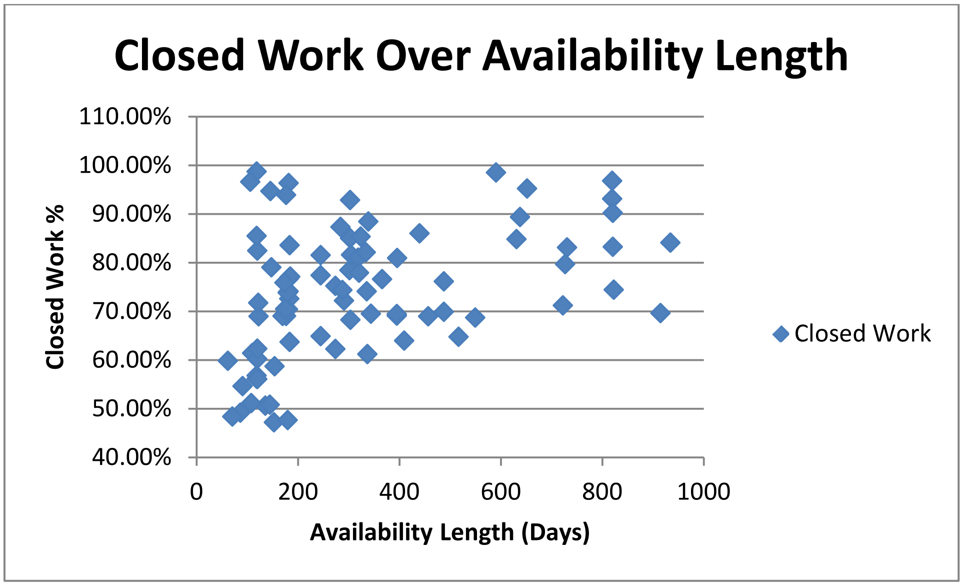

Figure 20. Closed Work over Availability Length

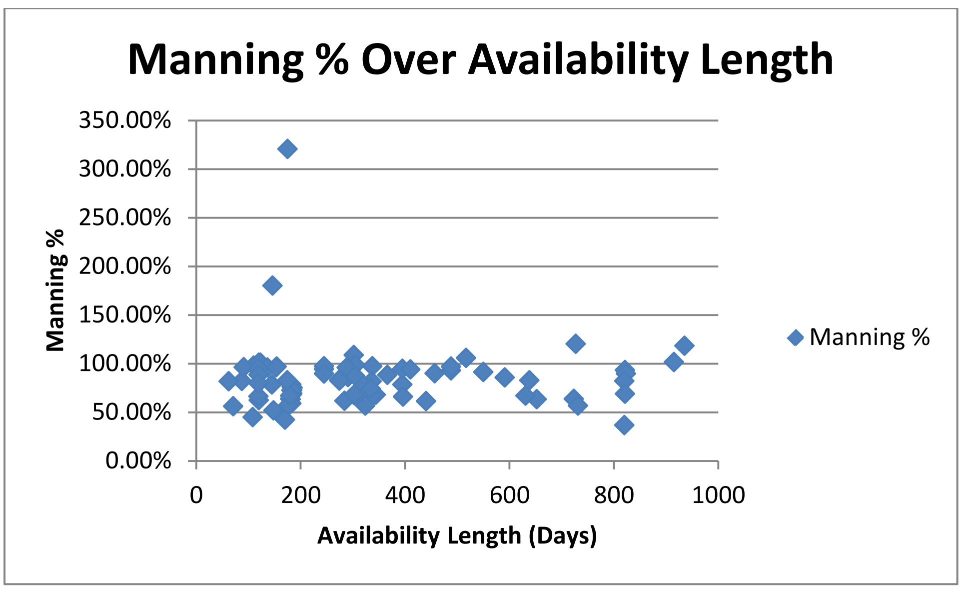

Figure 21. Manning Percentage over Availability Length

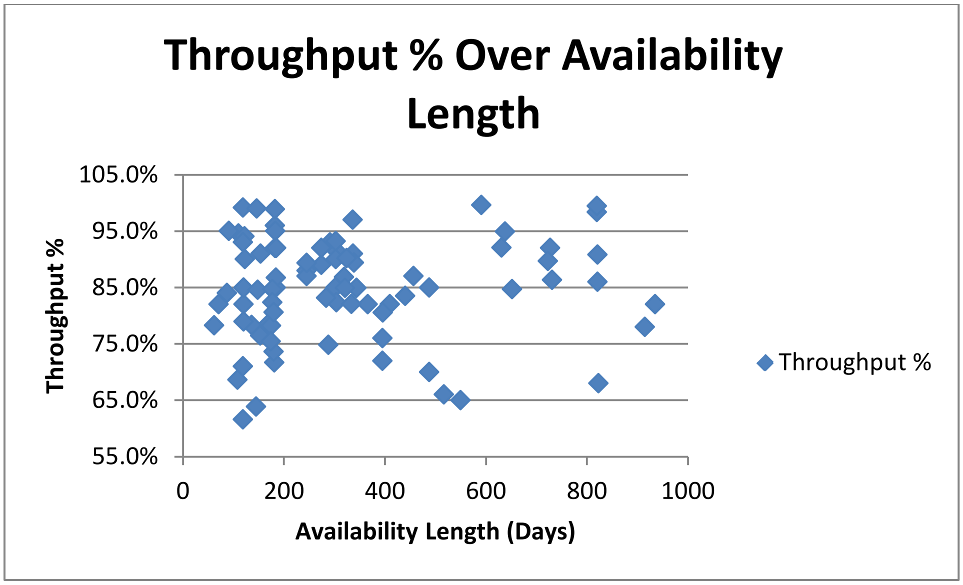

Figure 22. Throughput Percentage over Availability Length

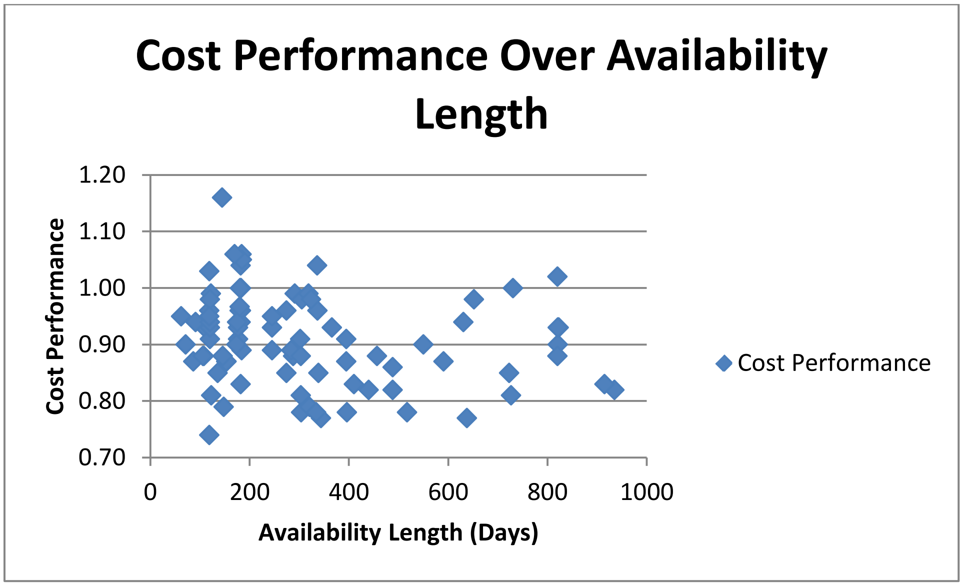

Figure 23. Cost Performance over Availability Length

APPENDIX C. ADDITIONAL PLOTS OF SHIPYARD METRICS PLOTS VERSUS ACTUAL COMPLETION TIME

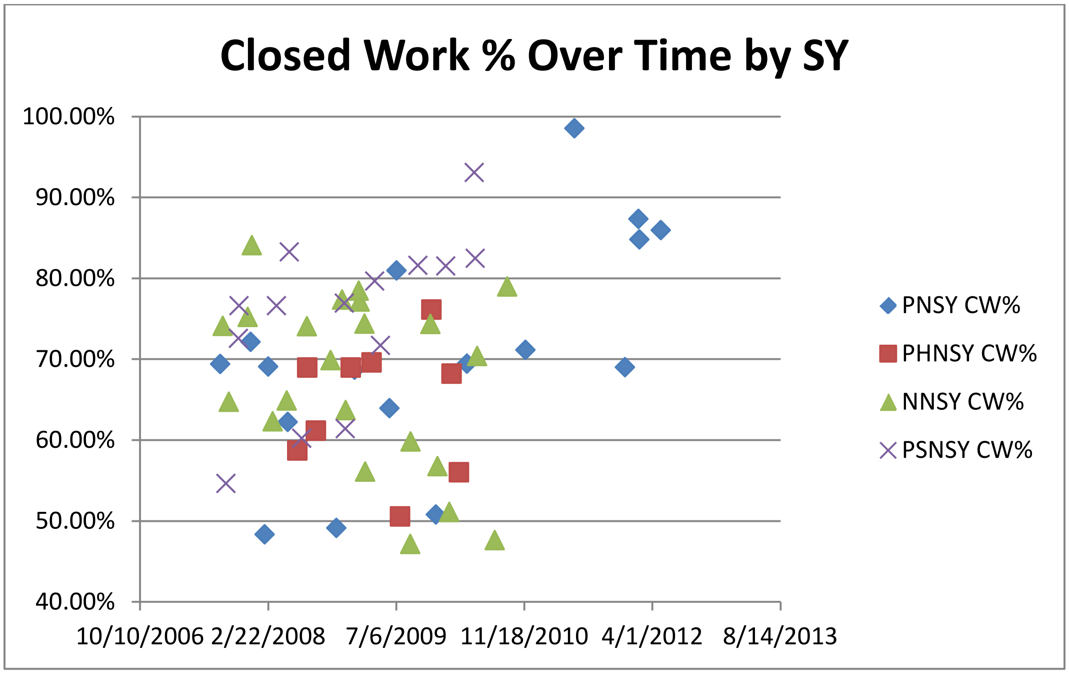

Figure 24. Shipyard Closed Work Percentage over Time

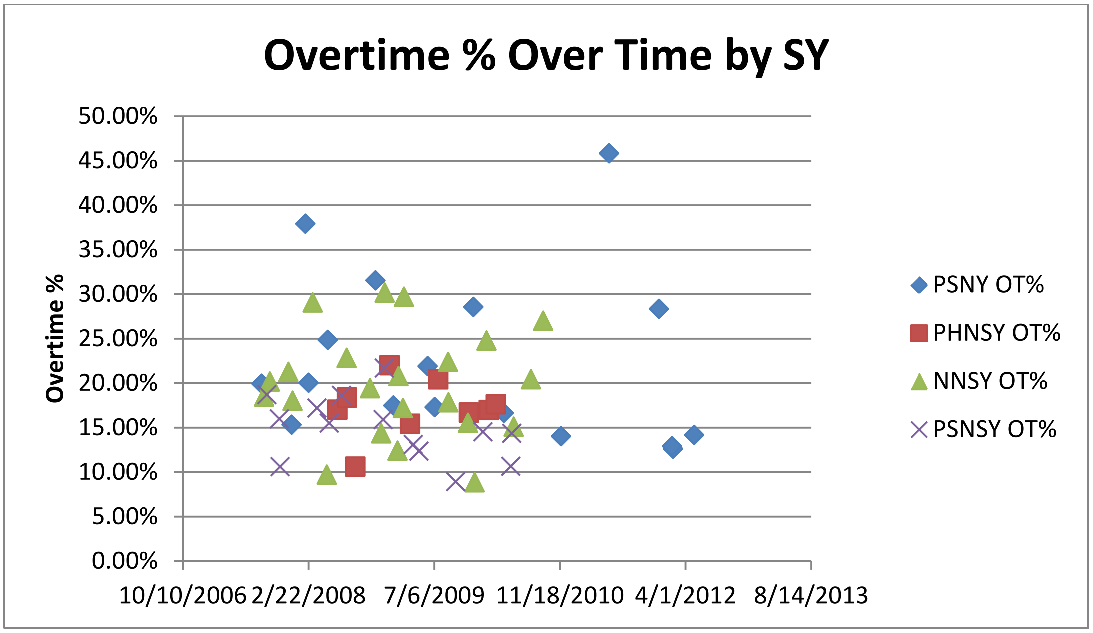

Figure 25. Shipyard Overtime Percentage over Time

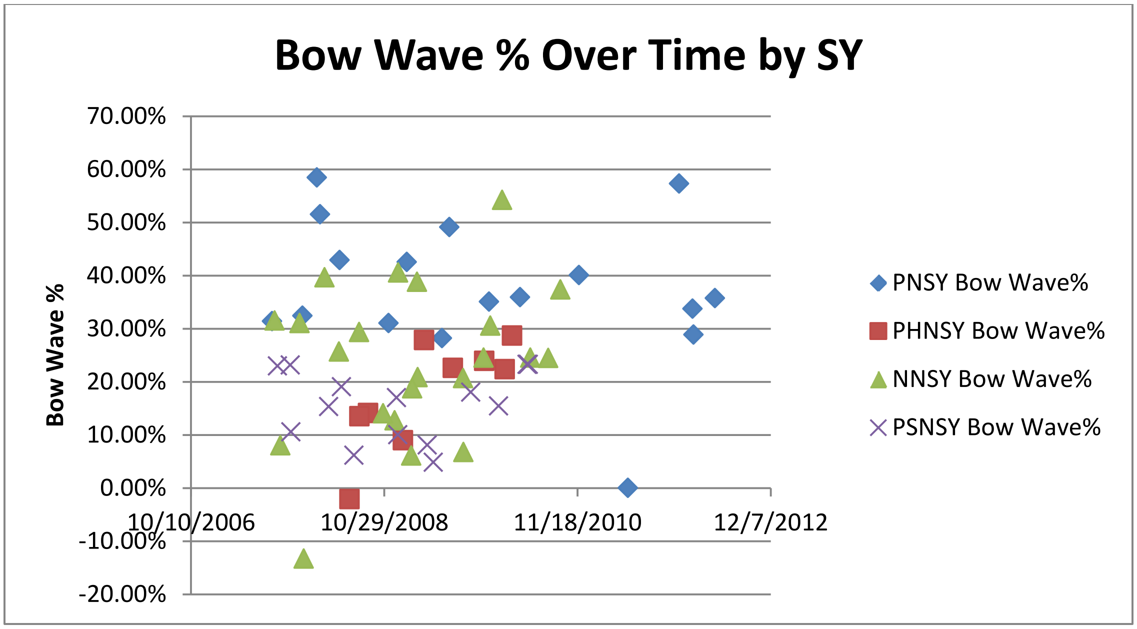

Figure 26. Shipyard Bow Wave Percentage over Times

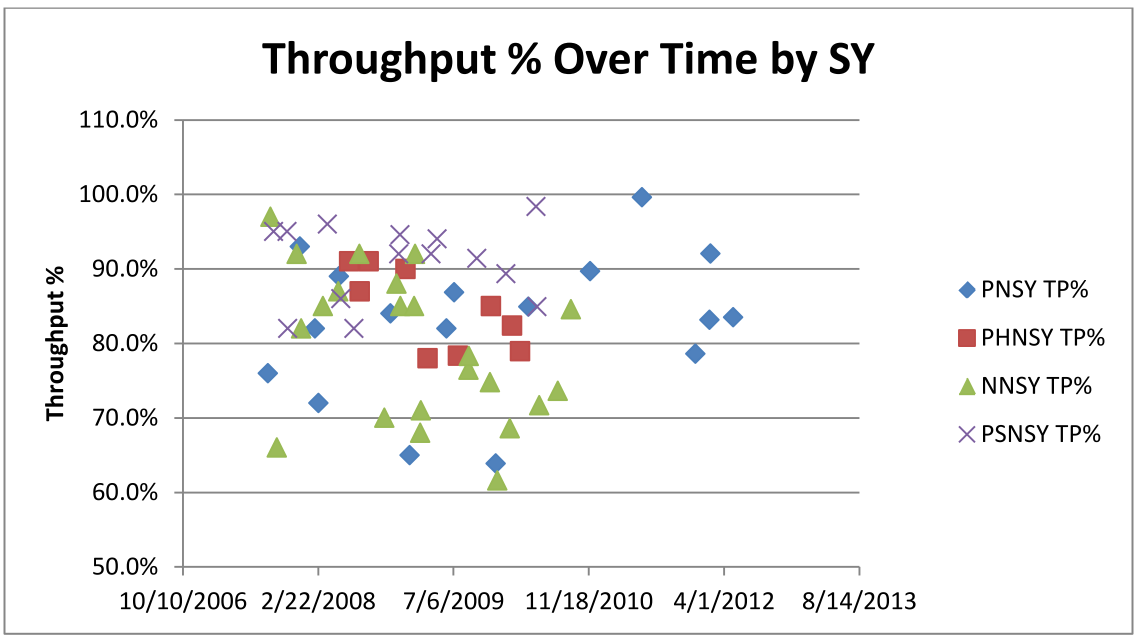

Figure 27. Shipyard Throughput Percentages over Times

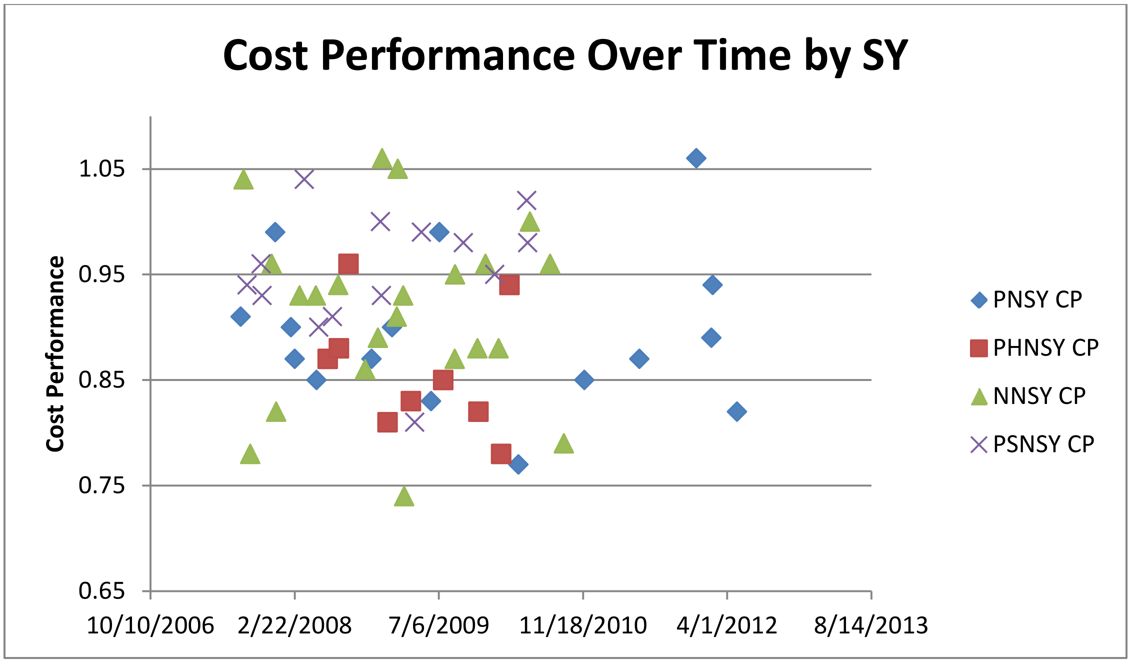

Figure 28. Shipyard Cost Performance over Time

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APPENDIX D. ADDITIONAL PLOTS OF METRICS CATEGORIZED BY AVAILABILITY LENGTH AS A FUNCTION OF ACTUAL COMPLETION TIME

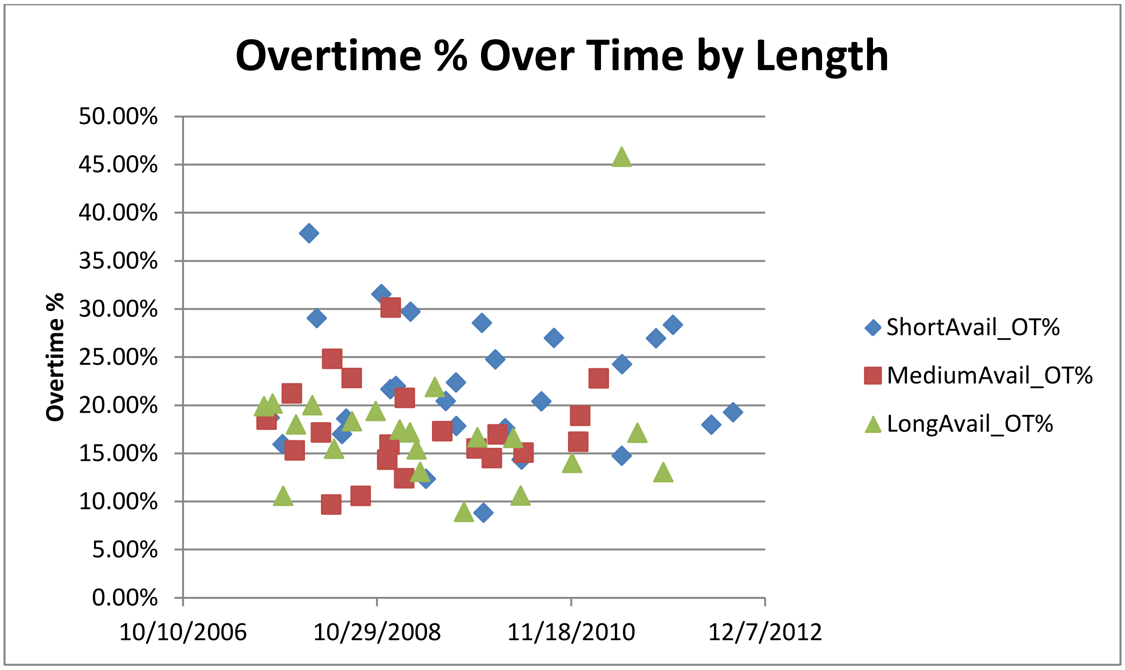

Figure 29. Availability Overtime Percentages over Time by Defined Length

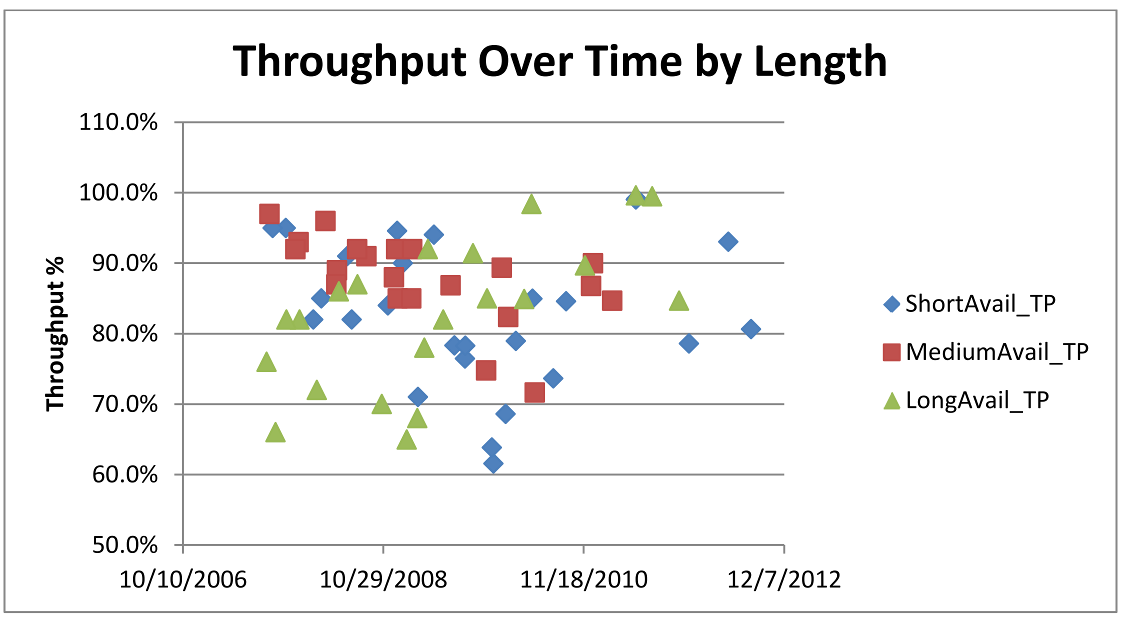

Figure 30. Availability Throughput Percentages over Time by Defined Length

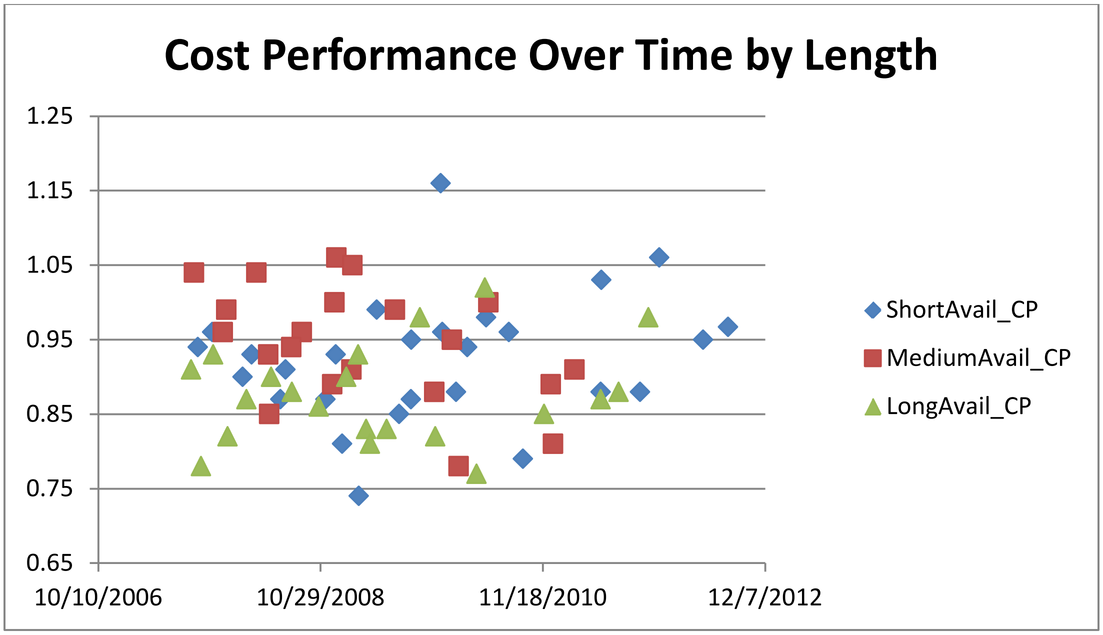

Figure 31. Availability Cost Performance over Time by Defined Length

APPENDIX E. WEEKLY AVAILABILITY METRIC PLOTS FOR THE FIRST 30 PERCENT OF THE AVAILABILITY

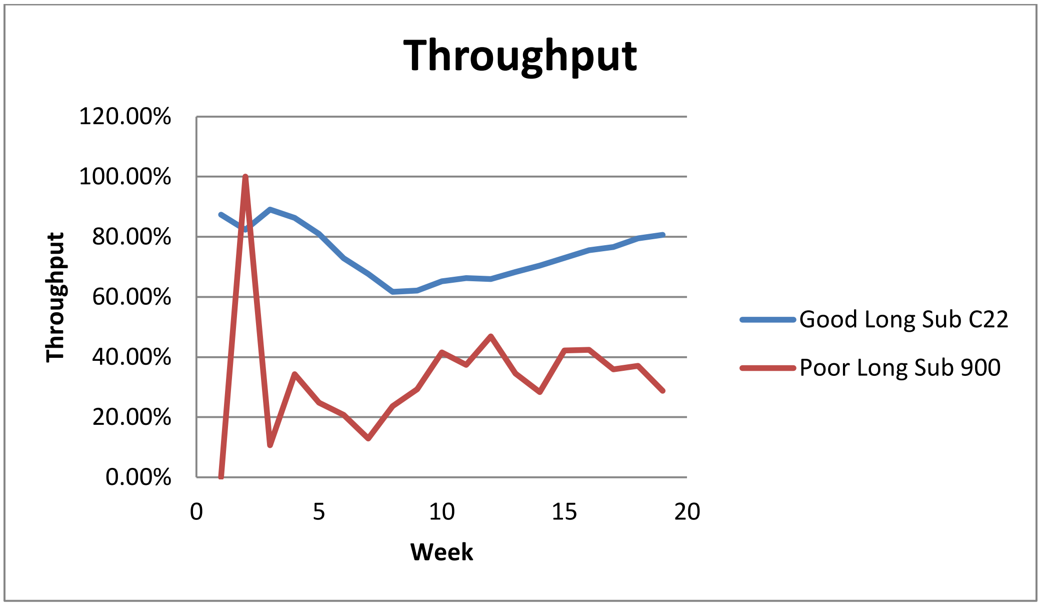

Figure 32. Long Sub Throughput Values over First Third of Availability

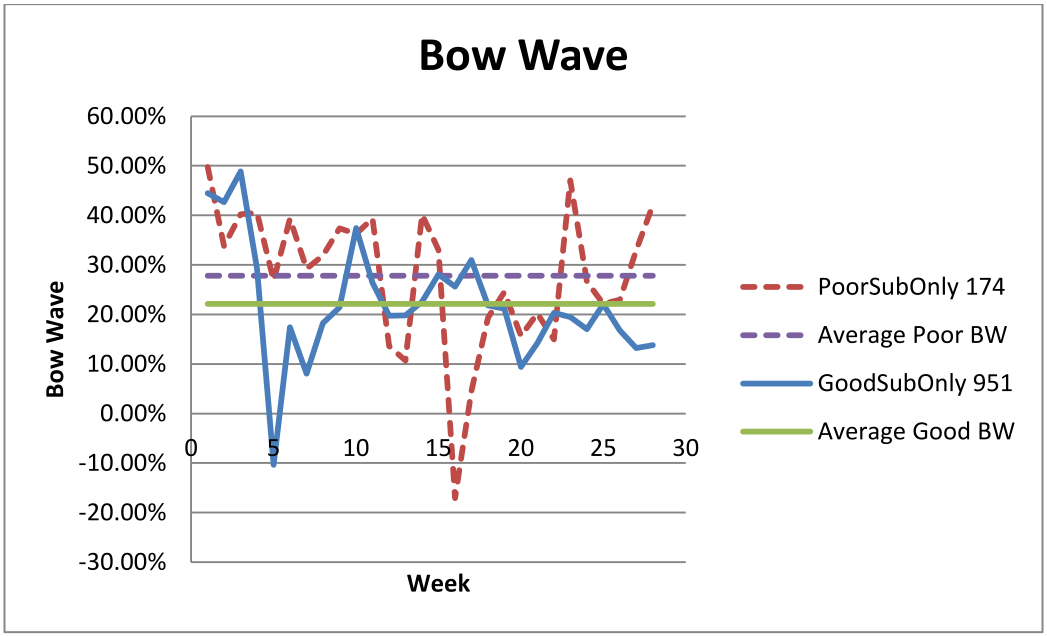

Figure 33. Sub-only Shipyard Bow Wave Values over First Third of Availability

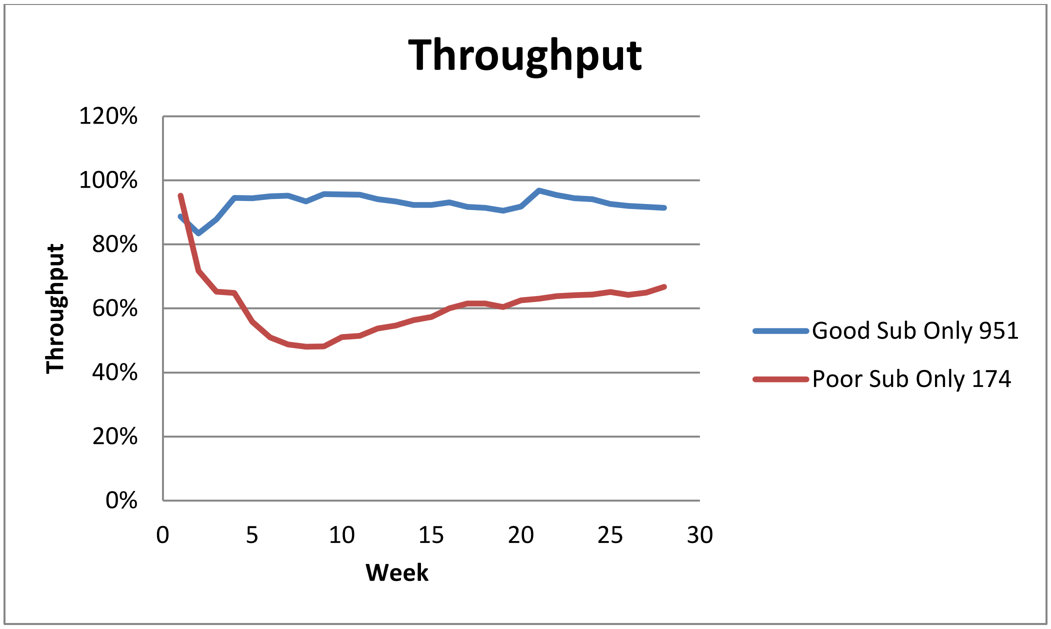

Figure 34. Sub-only Shipyard Throughput Values over First Third of Availability

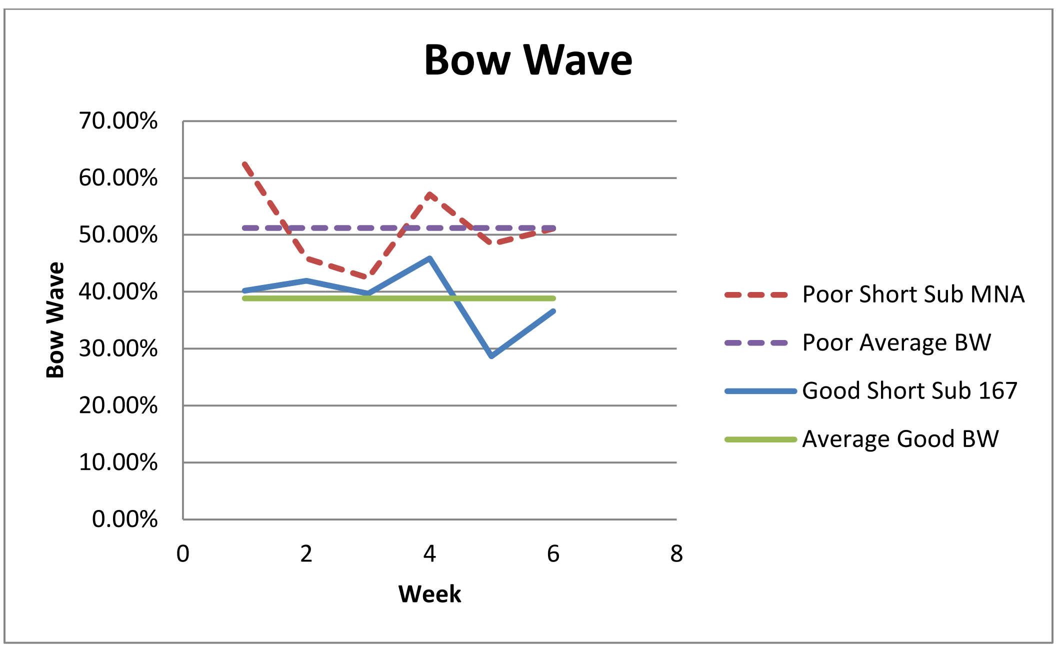

Figure 35. Short Sub Bow Wave Values over First Third of Availability

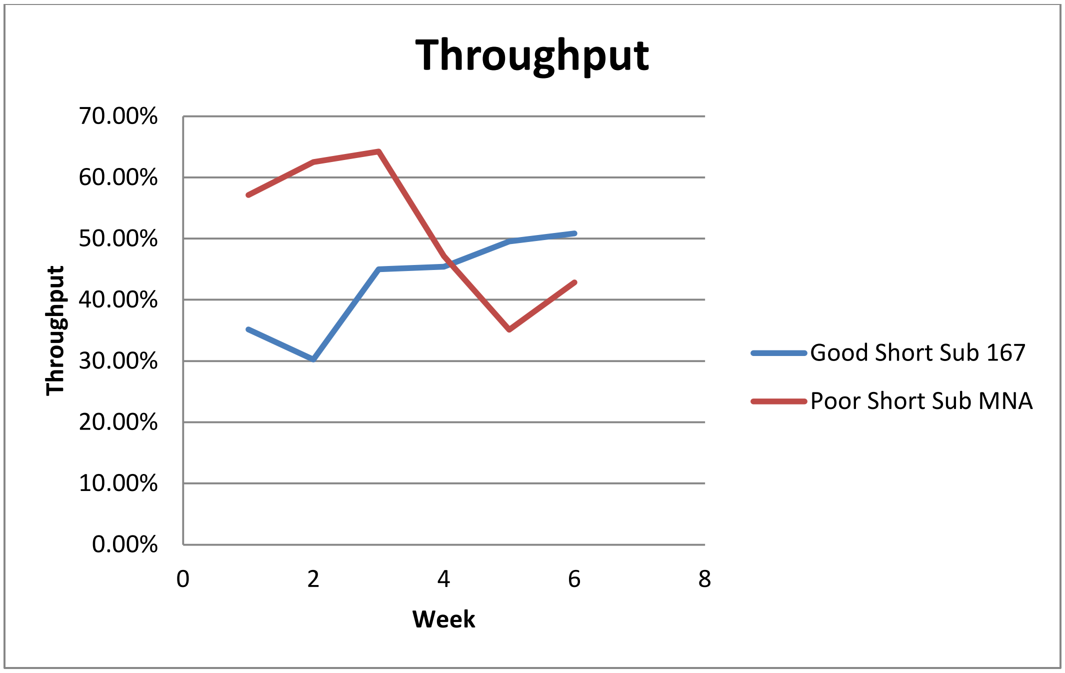

Figure 36. Short Sub Throughput Values over First Third of Availability

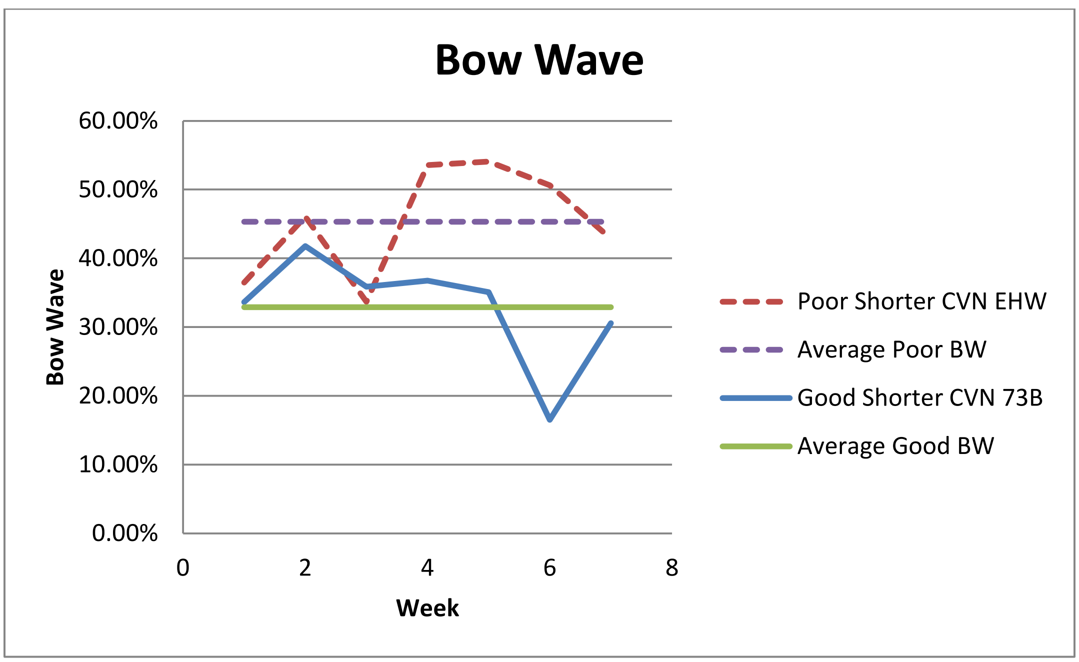

Figure 37. Shorter CVN Bow Wave Values over First Third of Availability

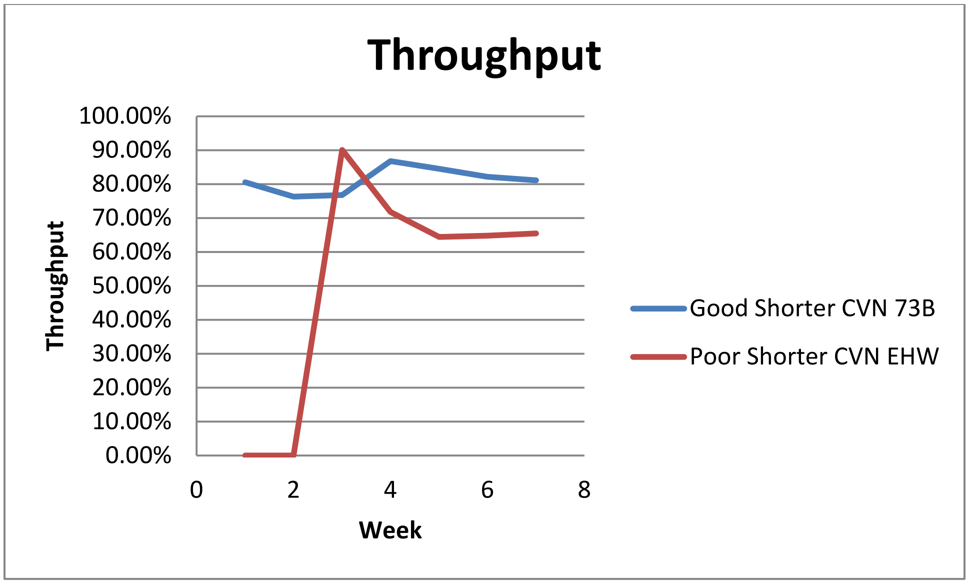

Figure 38. Shorter CVN Throughput Values over First Third of Availability

LIST OF REFERENCES

Caprio, Joseph L., and Daniel Leszczynski. 2012. *A preliminary investigation into CNO availability schedule overrruns*. Master's thesis, Naval Postgraduate School, Monterey, CA.

Hayter, A. 2007. *Probability and statistics for engineers and scientists,* 3rd ed. Belmont, CA: Duxbury.

Kerzner, Harold. 2009. *Project Management: A systems approach to planning, scheduling, and controlling*. 10th ed. Hoboken, NJ: John Wiley & Sons, Inc.

Naval Sea Systems Command. 2009. *Strategic business plan 2009–2013*. Washington DC: Department of Navy.

Naval Sea Systems Command 04X. 2006. *Implementation of Lean Release 2.0,* NAVSEA ltr 4855 Ser 04X/245. Washington DC: Department of Navy.

Naval Sea Systems Command 04X. 2007. *Implementation of Lean Release 3.0,* NAVSEA ltr 4855 Ser 04X/145. Washington DC: Department of Navy.

Naval Sea Systems Command 04X. 2012. *AIM-NG resource allocation*, Powerpoint slides. Norfolk, VA: Department of Navy.

Naval Sea Systems Command 04X. 2012. "Project management metrics used for performance measurement and control." In *AIM-NG process manual*. Washington DC: Department of Navy.

Naval Sea Systems Command 04X. 2012. "Work in process control (WIPCON)." In *AIM-NG process manual*. Washington DC: Department of Navy.

Naval Sea Systems Command 04Z (Director, SUPSHIP Management Group). 2011. *SUPSHIP organizational manual. Chapter 1: Mission and organization*. Washington DC: Department of Navy.

Office of the Chief of Naval Operations N00 (Chief of Naval Operations). 2013. "Direction regarding the continuing resolution and sequestration," NAVADMIN 005/13. Washington DC: Department of Navy.

Office of the Chief of Naval Operations N43 (Director, Fleet Readiness). 2010. "Representative intervals, durations, and repair mandays for depot level maintenance availabilities of U.S. Navy Ships." In Operational Navy Notice 4700. Washington DC: Department of Navy.

Office of the Chief of Naval Operations N431 (Fleet Readiness and Logistics). 2010. *Maintenance policy for United States Navy ships*, Operational Navy Instruction 4700.7L. Washington DC: Department of Navy.

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